5 The Sextant

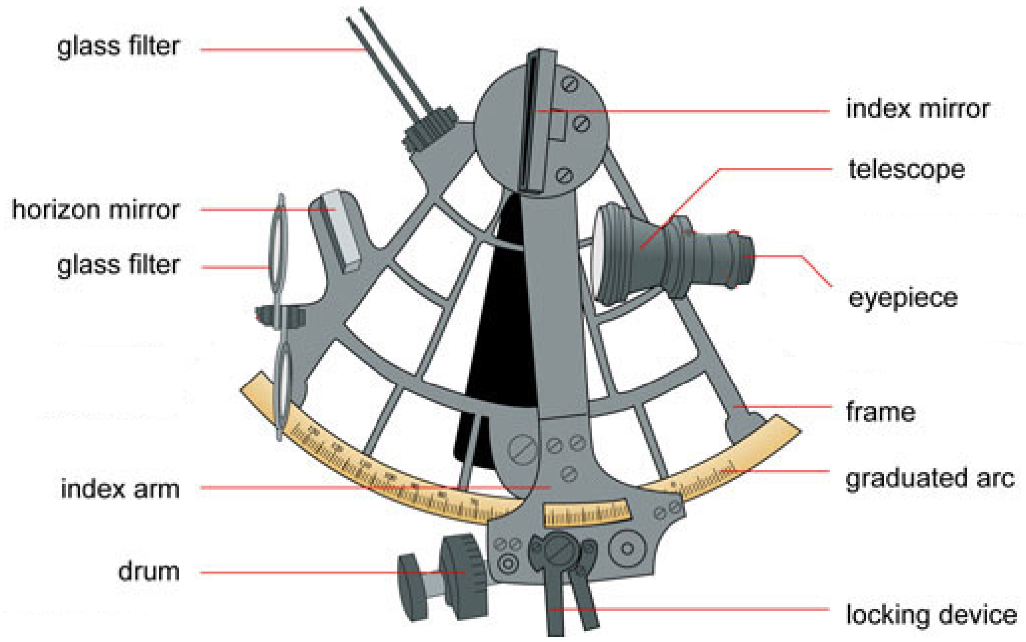
5.1 Objective

By the end of this section you will know the basic components of a marine sextant, some alignments that need to be checked and some simple adjustments that need to be made. You will also be introduced to the correct way to use a sextant to measure vertical angles.

5.2 Overview

Sextants are used to measure angles. There are many good books that describe, in detail, how sextants work so this material will only deal with the essentials. One good source is Bowditch, Chapter 16 and for your convenience a copy is included on the course CD.

The main components of a sextant are shown in the diagram.



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5.3 Sextant Errors

There are three errors which can be controlled by user adjustment:

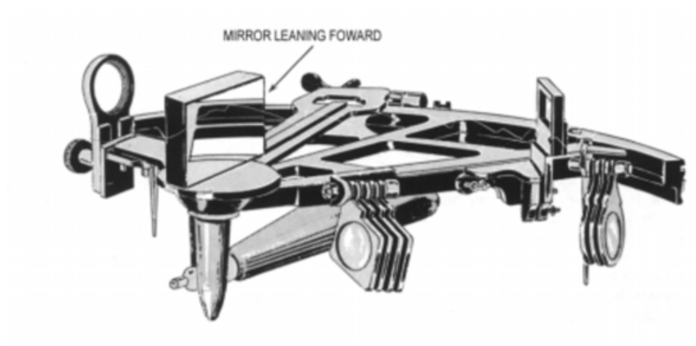
i. Perpendicularity error
ii. Side error
iii. Index error.

These errors are well described in Bowditch (Article 1612, a précis is reproduced below; full article can be found on the course CD) and you will also be shown how to check these during the course.

5.3.1 Adjustable Sextant Error

The navigator should measure and remove the following adjustable sextant errors in the order listed:

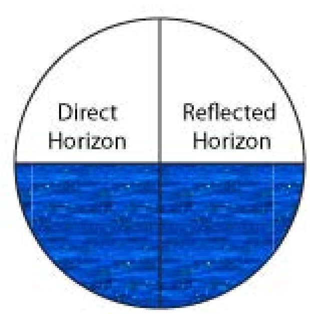
5.3.2 Perpendicularity Error:



Adjust first for perpendicularity of the index mirror to the frame of the sextant. To test for perpendicularity, place the index arm at about 35° on the arc and hold the sextant on its side with the index mirror up and toward the eye. Observe the direct and reflected views of the sextant arc, as illustrated. If the two views are not joined in a straight line, the index mirror is not perpendicular. Make the necessary small adjustment using screws behind the index mirror.

5.3.3 Side Error:

An error resulting from the horizon glass not being perpendicular is called **side error**. There are three methods of checking for side error, the simplest is described here. Using the sextant vertically, as in observing the altitude of a celestial body bring the reflected image of the horizon into coincidence with the direct view until it appears as a continuous line across the horizon glass as shown.



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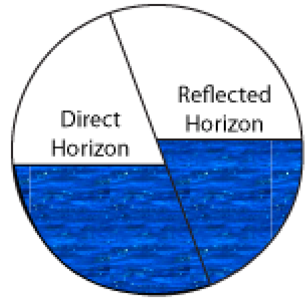
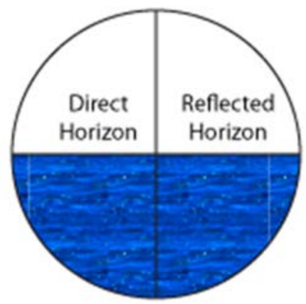
Then tilt the sextant right or left. If the horizon still appears continuous, the horizon glass is perpendicular to the frame, but if the reflected portion appears above or below the part seen directly, the glass is not perpendicular (see diagram). Make the appropriate adjustment using screws behind the horizon glass.



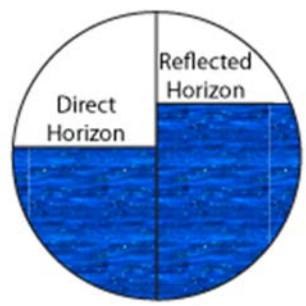
5.4 Index Error and Index Correction

Index error is the error remaining after the navigator has removed perpendicularity error, and side error. The index mirror and horizon glass not being parallel when the index arm is set exactly at zero is the major cause of index error. To test for parallelism of the mirrors, set the instrument at zero and direct the line of sight at the horizon. Adjust the sextant reading as necessary to cause both images of the horizon to come into line. The sextant's reading when the horizon comes into line is the index error.

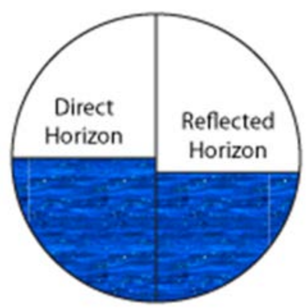


Index error is the most commonly experienced error and every time you use the sextant you should check it. If using a plastic sextant check it frequently during your sight taking session and definitely at the beginning and end as a minimum. This is easy to do all you need is a star or the horizon. The diagrams indicate the use of the horizon.

Set the sextant to zero degrees. Look at the horizon and if the direct view of the horizon (left side) and the reflected image of the horizon (right side) are in line as shown in the top diagram the index error is zero. However it almost never is!



If the view looks like the middle diagram slowly turn the vernier drum until the images are in line as shown in the top diagram. Read the value from the sextant and note it on your sight worksheet.



If you go too far when bringing down the reflected image or if the view at the start looks like the lower diagram turn the vernier drum back until the view looks like the middle diagram. Bring the reflected image down again until the two images are just in line. Read the value from the sextant and note it in your sight worksheet.

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Always adjust the vernier drum to bring the reflected image down to be in line with the direct image. If you go too far take the object back up above the horizon and bring it down again. This will minimize any error in the vernier drive.

If you find the index error to be more than a small number of minutes of arc (6' for example) the sextant should be adjusted. However do not adjust too often as this can cause wear in the adjustment devices and lead to further problems.

The angle you read from the sextant when the images are in line is the **Index Error**. When measuring angles you will apply the same value, with the opposite sign, as the **Index Correction**. There are some exercises below to give you plenty of opportunity to apply index corrections.

These images are what you would see with a split horizon mirror, sometimes called a traditional mirror. Some modern sextants have a whole horizon mirror in which case the reflected image is superimposed on the direct image instead of alongside it. Ynot Sailing has both types of sextants and you will be given the opportunity to see both during the course.

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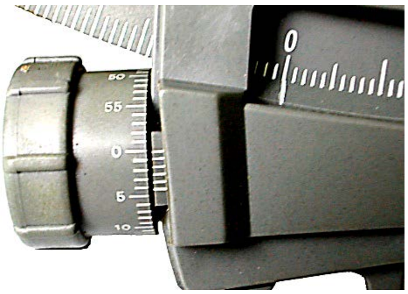
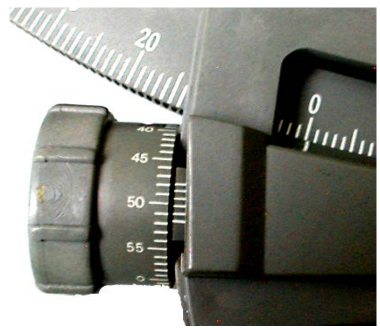
OK so you have adjusted the vernier to bring the direct and reflected images in line. The series of pictures below illustrate the various conditions that could exist on the sextant.



In the picture to the left the index error is zero so there is no correction to be made. All measured angles will be correct. This does not happen often (ever?).

In the picture to the right the sextant reads 359° 47.8’ or, when expressed relative to zero, 12.2’ off. With this index error you must add 12.2’ to all the angles you measure as the scale reading will be low by this amount.



In the picture to the left the sextant reads 0° 35.4’ on. All measured angles will be this amount higher than they really are so you must subtract 35.4’ to get an accurate reading.

These index errors are excessive and in practice this sextant would be adjusted before being used to take sights. Normally index errors are just a few minutes.

One expression you may hear is, “if it’s on take it off” and “if it’s off put it on”. Let’s translate this into plain English. This is what it means. When checking for index error if your reading is “on” the scale ie above zero you need to take “off” that amount as the index correction. This is illustrated in the third picture. If on the other hand the reading is “off” the scale, ie below zero you need to add “on” that amount as the index correction. This is illustrated in the second picture.

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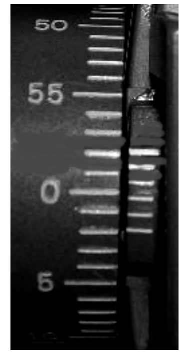
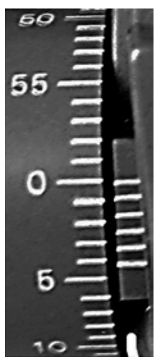
5.5 Index Error and Correction Exercise

In all instances the degrees mark is close to zero.

Index Correction __________



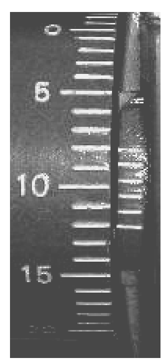
Index Correction __________



Index Correction __________

Index Correction __________

Index Correction __________



Index Correction __________

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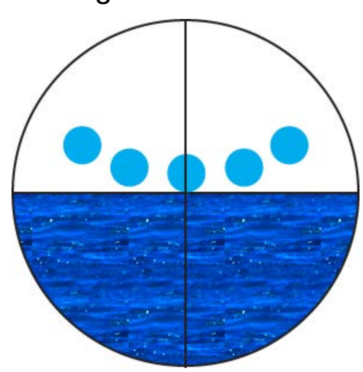
5.6 Using the Sextant

For your first sessions using a sextant plan on taking Sun sights from a south facing beach (north facing if you are in the southern hemisphere). A good time to start would be about 11 in the morning and plan to take sights till a little after noon. This will give you plenty of time to become familiar with the operation of the sextant in daylight. Once you have mastered using the sextant you can then proceed to taking sights during twilight when of course the time period is much shorter. If there is no convenient beach start by using a neighbour's roof or similar horizontal surface while becoming familiar with the operation of the sextant.

1. Remove the sextant from its case. Hold it by the frame NEVER by the index arm or graduated scale.
2. You will need both hands to operate the sextant so if you are on a boat find a position where you can be stable and safe without holding on. This is one time the saying "one hand for the ship and one hand for you" does not apply. Sometimes, depending on the conditions and the boat, you need to be sitting down to be safe.
3. The sextant should have a safety lanyard attached. As soon as you remove the sextant from its case put the lanyard around your next to prevent the sextant from being damaged if accidently dropped.
4. Hold the sextant by gripping the handle with your right hand. You operate the locking device and vernier drum with your left hand.
5. Set the index arm to zero; check and note the index error (see previous section).
6. **IMPORTANT!** Drop some shades over the mirrors before proceeding. If you forget this step you will damage your eyes.
7. With the sextant still set to zero point the sight tube at the Sun.
8. With the Sun in view open the locking device and bring the image of the Sun slowly down to the horizon.
9. As you approach the horizon but with the Sun still a little above it, rock the sextant to ensure you have it vertical – the image will be at the lowest part of the arc at this point. With the sextant vertical bring the lower edge (lower limb) of the Sun down so it just kisses the horizon. You will have to remove some of the horizon mirror filters to be able to see the horizon.



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10. At the instant the Sun’s edge (lower limb) is on the horizon note the time in reverse order i.e. seconds first, then the minutes, then the hour. Initially it is a good idea to have a helper who can record the time for you. As you get more experienced you will be able estimate quite accurately the number of seconds it takes you from the exact moment you bring the object down to the horizon and looking at the clock. Next record the sextant angle. Transfer the data to your sight worksheet. A suitable layout can be found on the course CD but of course you could design your own. You will learn what to do with this information in later sections.

Bringing a star down to the horizon is more of a challenge as the pinpoint of light is easily lost during the process especially if you are using a telescope which, of course, has a limited field of view. It takes a lot of coordination but is definitely worth practicing.

An alternative technique involves pre-calculating the angle and bearing, remembering to allow for variation, you expect for the star; set the sextant close to the angle and point the sextant towards the horizon in the direction of the calculated bearing. The star will appear and can be brought down to the horizon in the normal way. You will learn how to do the calculation in a later section.

Another technique involves using the sextant in an inverted fashion where you keep the telescope pointed at the star and bring the horizon up to the star. Once you have the sextant set so they are both in view leave the index arm where it is and turn the sextant the right way up. Point the sextant at the horizon in the direction of the star and use the fine adjustment to bring the body to the horizon as described above.

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6. Time

6.1. Objective

By the end of this section you will know more about time than you thought possible. In particular you will learn how time and longitude are related, understand and apply time zones, time signals and how to correct for watch errors.

6.2. Greenwich Mean Time

All Nautical Almanac data are based on the date and time at Greenwich. Greenwich Mean Time (GMT) is now called Universal Time (UT). In these notes the term GMT will be used throughout as it is a good reminder to think in terms of Greenwich as the reference when extracting information from the Nautical Almanac. Just remember that if you see UT anywhere else it is the same thing as far as you are concerned.

Before you open the Nautical Almanac to look up any information about celestial bodies you must know the Greenwich equivalent to your local time. There are two ways to do this:

a. Learn how to convert your watch time to GMT, or

b. Always have the watch you use for celestial navigation set to GMT.

To convert your watch time to GMT use the Zone Descriptor (ZD). This is covered in the next section.

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6.3. Zone Time

The Earth rotates 360º in 24 hours. That's 15° every hour.

360°/24 hours = 15°/hour.

The Greenwich meridian is longitude 0° and is the centre of the Z time zone. If you hear reference to Zulu time it has nothing to do with the African tribe ☺. The edges of this zone are longitude 7.5°E and 7.5°W. Each time zone is 15° or 1 hour wide.

There are 24 time zones, each has a letter designation. On land some zone boundaries are distorted for geo-political or commercial reasons. This is of no concern to the sailor while at sea though it may affect him when ashore. Tide tables, for example, use standard (zone) time for the area they cover.

The Zone Description (ZD) is the number of hours to be added to the zone time to get GMT for that zone. The ZD is positive for west longitudes and negative for east longitudes.

E.g. If you watch time is 13-43-27 and the ZD is +10 the GMT is 23-43-27. If the ZD is – 4 then GMT would be 09-43-27.

As you already know there are 24 one-hour time zones each 15° wide. Your longitude determines the time zone you are in. The Greenwich meridian is the starting point so if you are in Montreal (45º 30'N 73º 35'W) which is between 67.5°W and 82.5°E (ZD +5) your watch will indicate GMT - 5 hours in the winter months and one hour less when daylight savings time is in use. Daylight saving time is not used at sea and will be ignored from now on.

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6.4. Watch Time

Your watch is normally set to give the local time. Anyone who has travelled large distances (North America to Europe for example) will attest to the fact that you need to have your watch set to the time zone you are in rather than the time of your home location.

For celestial navigation purposes you need to be able to convert the time on your watch (zone time) to GMT and vice versa. To convert watch time to GMT first determine which zone you are in from your longitude. This can be done by dividing your longitude by 15 and rounding the answer to the nearest whole number; west being +ve and east –ve or by using the table below.

GMT = Watch time + (ZD).

Please note some Zone Descriptors are negative.

If your longitude is		West Longitude		East Longitude	
Greater than	Less than	From Zone time to UT			
		ZD	Suffix	ZD	Suffix
0	7 ½	0	Z	0	Z
7 ½	22 ½	+1	A	-1	N
22 ½	37 ½	+2	B	-2	O
37 ½	52 ½	+3	C	-3	P
52 ½	67 ½	+4	D	-4	Q
67 ½	82 ½	+5	E	-5	R
82 ½	97 ½	+6	F	-6	S
97 ½	112 ½	+7	G	-7	T
112 ½	127 ½	+8	H	-8	U
127 ½	142 ½	+9	I	-9	V
142 ½	157 ½	+10	K	-10	W
157 ½	172 ½	+11	L	-11	X
172 ½	180	+12	M	-12	Y

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6.5. Time Signals

Many nations broadcast extremely accurate time signals using short wave radio. The table shows the frequencies for the North American stations. They can be received using a modestly priced short wave radio receiver.

Country	Call Sign	Frequencies (MHz)
Canadian (Ottawa)	CHU	3.33, 7.335, 14.670
US (Boulder Colorado & Hawaii)	WWV and WWVH	2.5, 5.0, 10.0, 15.0, 20.0 25.0

6.6. Watch time Correction

Use these time signals to regularly check your watch. If you have a GPS you can also use that to get accurate time checks. Do not adjust your watch each time but note the difference. Over a period of time you will establish the trend for your watch. The difference between your watch time and the time signal is called watch error and is applied during the sight reduction process to ensure the correct time is used when looking up data in the almanac. If the watch is fast the error must be subtracted and vice versa.

HHU Hint *The sight reduction form is annotated (f-/s+) to make it easy for you.*

Many textbooks refer to the ship's chronometer and a hack watch. In days before accurate electronic watches, an expensive and highly accurate mechanical time piece (the chronometer) was kept in a safe, protected, and stable environment to minimise changes due to temperature, vibration, etc. The navigator would use a separate watch (the hack watch) which he would compare to the chronometer regularly. To be classified as a chronometer a time piece must undergo rigorous tests. They are of course expensive and not many manufacturers bother any more. Having said that, a relatively inexpensive digital watch is just as accurate as many chronometers, especially if you make up your own calibration sheet.

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6.7. Longitude – Time Conversion

The Sun takes 24 hours to go around the Earth (remember Copernicus was wrong ☺); that's equivalent to 15° every hour. (360°/24 = 15°/hour). Get your calculators out and based on what you now know complete the table

Arc / Time.

Arc	360°	15°	1°	60'	15'	1'
Time	24 Hrs					

__HHU Hint__ Minutes and seconds of arc are angles and different from minutes and seconds of time even though they are spelt the same.

OK that was simple enough. So knowing what you now know convert 137° 36.5'W into an equivalent time. Use the table below for the solution.

137° = ___ minutes = __ hours __ minutes __ seconds
36.5' = ___ seconds = __ hours __ minutes __ seconds
Total = __ hours __ minutes __ seconds.

Although this is simple enough it has been known to cause brain ache, thankfully there's an easier way. The Nautical Almanac has an Arc to Time conversion table on page (i). There is a copy in the Nautical Almanac extract included in this material. Look up the degrees first then the minutes and add the two times together. You will notice that there are only 4 columns for decimal parts of the minutes (0.00, 0.25, 0.5, and 0.75). Just use the closest, there's only a second between them anyway.

6.7.1. Longitude to Time Conversion Exercise

Try these just for the fun of it:

Arc	Time	Arc	Time
045° 16.7'		096° 45.0'	
124° 37.2'		268° 45.9'	
179° 32.4'		347º 12.3'	

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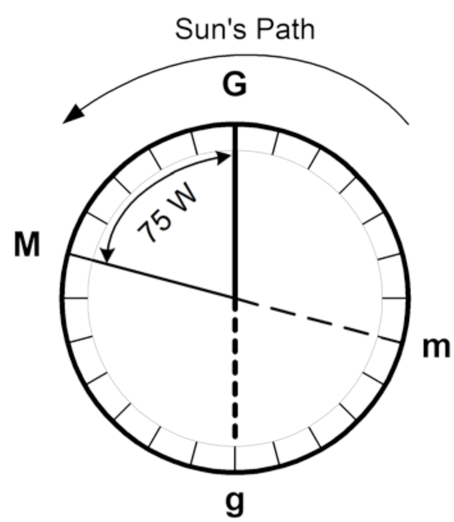
6.8. Time Diagrams

Time diagrams are simple sketches showing the relationship between **time** and **longitude**. They help to visualise the relationships between the local time, Greenwich Mean Time (GMT), and the time associated with the celestial body. They can also be used to determine if the Greenwich date is the same as, or one day ahead or behind, the local date. It is the **Greenwich time** and **date** that must be used when looking up data in the Nautical Almanac.

As previously mentioned, for the purposes of learning celestial navigation, you imagine that Copernicus was wrong and the Earth is the centre of our universe. With that in mind you are going to develop a time diagram for the Sun. Exactly the same process can be used for any celestial body.

The diagram is a view of the Earth looking up at the South Pole. Each tick mark is the centre of a time zone. The Greenwich meridian is shown with a solid line and is labelled "**G**". The complement of the Greenwich meridian, called the lower branch is shown with dashed line and is labelled "**g**". This is also called the International Date Line.



Assume you are an observer and located somewhere on the meridian 75° west. The upper and lower branches are shown as "M" and "m" respectively.

The 75°W annotation on the diagram could just as easily have been labelled 5 hours.

Conventionally in timing diagrams the observer's meridian M is shown at the top. That is how you will see it in most, if not all, text books. I have not been able to find any reason or rationale for this convention. Personally I find it preferable to put the Greenwich meridian on top; it again reminds me that everything uses Greenwich as the reference in the Nautical Almanac. Try both and see which you prefer.

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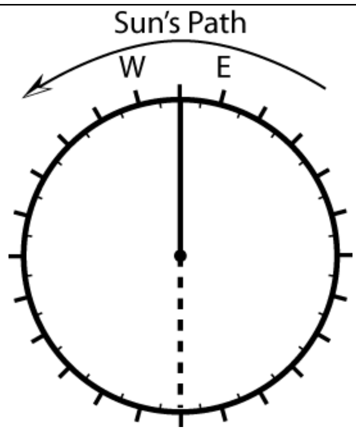
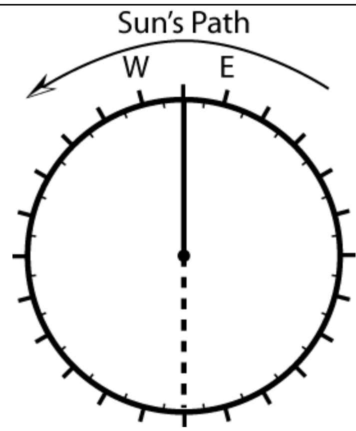
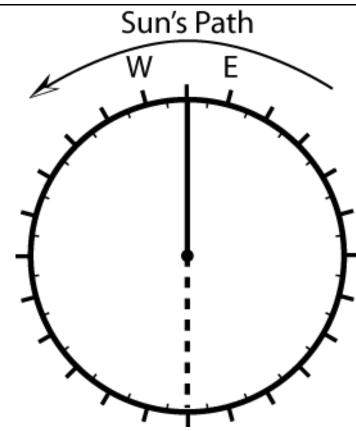
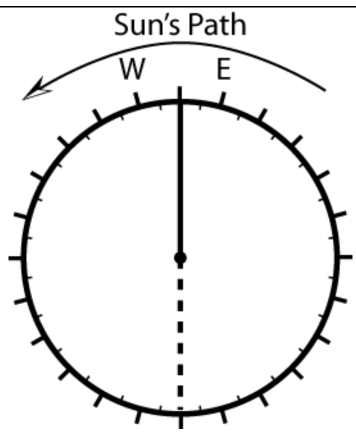
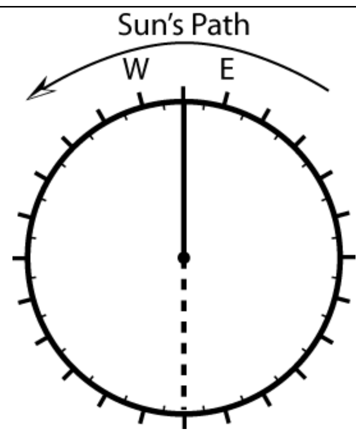
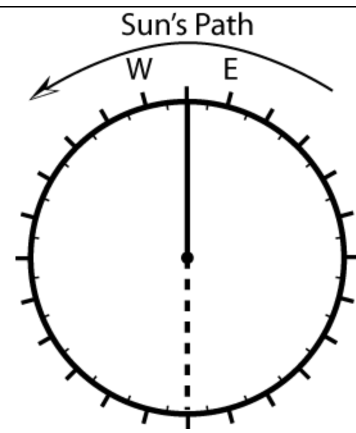
6.8.1. Timing Diagrams Exercise

To each of the time diagrams add the upper and lower branches for observers located at the indicated longitudes. Label the angular difference as a time.

105° East	090° West	060° East
		

140° West	128° East	025° West
		

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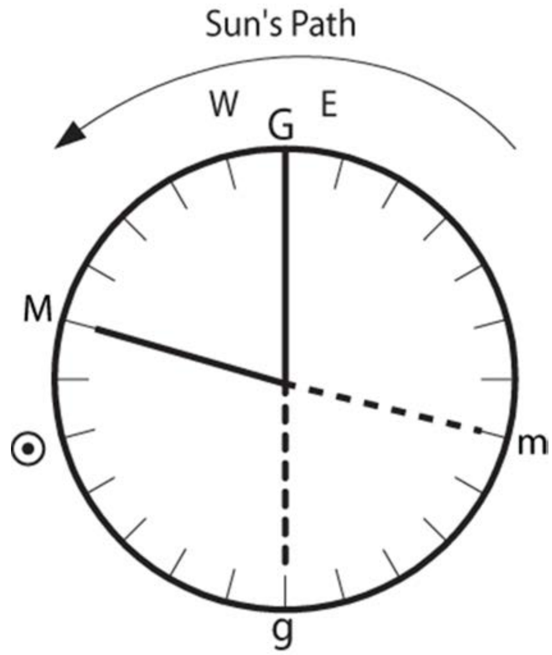
Now let's go to the next step by adding the position of the Sun to the time diagram.

The symbol for the Sun is ⊙ and has been added to the time diagram. Can you tell what time it is at M?



If the Sun had been at M it would have been local noon; this is not necessarily 12 o'clock watch time for several reasons that will be explained later. From the Arc / Time section that you completed a little earlier you will remember that each 15° segment represents 1 hour. So in this case the Sun passed the meridian 2 hours ago (post meridian = pm); the time is 2 o'clock in the afternoon (2pm, 14-00-00).

So if the Sun was located at **m** what would be the time at **M**? Midnight!

Similarly if the Sun was at G it would be noon at Greenwich and if at g it would be midnight.

So as the Sun crosses the lower branch of the Greenwich meridian (g) the Greenwich date changes. Similarly as the Sun crosses the observers lower branch (m) the local date changes.

Another way to place the Sun in this example would have been to work in the 24-hour clock. 2pm is 14-00. Each 15° degree segment on the time diagram represents 1 hour. So starting from the observer's lower branch count 14 tick marks counter clockwise and place the Sun.

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Timing Diagrams an alternate View

First some reminders:

Copernicus was wrong. The Earth is the centre of our universe and everything, including the Sun, rotates around us.

The MEAN Sun rotates around the Earth at a rate of 15^0/hour from east to west.

Time is determined by the position of the Sun.

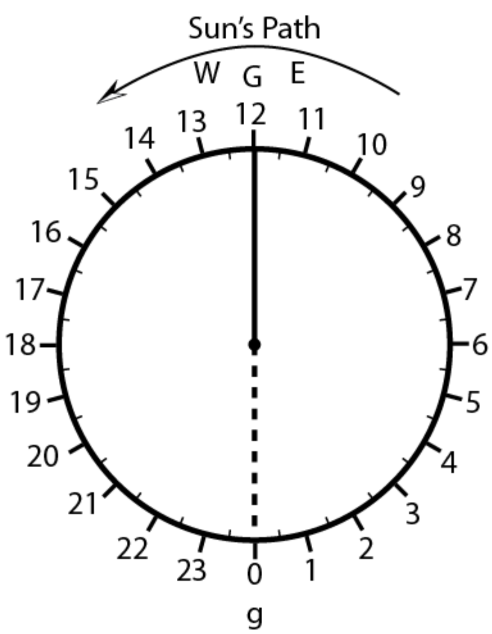
12 o'clock on your watch occurs when the mean Sun is in line with the **central** meridian of your time zone (except when DST is in use).

The central meridians of all the time zones are shown as short lines on the outside of the time diagram circle.

The Greenwich and observer's meridians are shown on the timing diagram with solid lines and are labelled with a capital letter (G for Greenwich, M for the observer). They are called the upper branches. The lower branch of the meridian is shown with a dashed line and labelled with a small g or m.

Midnight occurs when the mean Sun is in line with the lower branch of the meridian (dashed line labelled g or m respectively).

Time Diagrams as 24 Hour Clocks



The first thing to notice about this clock face is that it runs anti-clockwise. The reason this is done is so that the orientation of longitude East and West is maintained; East to the right, West to the left. The second thing is that it is split into 24 hours not 12. Some military clocks are actually like this except they run in a normal clockwise direction.

This timing diagram shows ONLY the upper and lower branches of the Greenwich meridian. Time increments as the Sun rotates around the Earth. When the Sun is in line with g (Greenwich meridian lower branch) the time at Greenwich is 0 (midnight). When the Sun is at G (Greenwich meridian upper branch) it is 12 o'clock (noon) at Greenwich and so on. The date at Greenwich changes when the Sun passes the lower branch i.e. at midnight.

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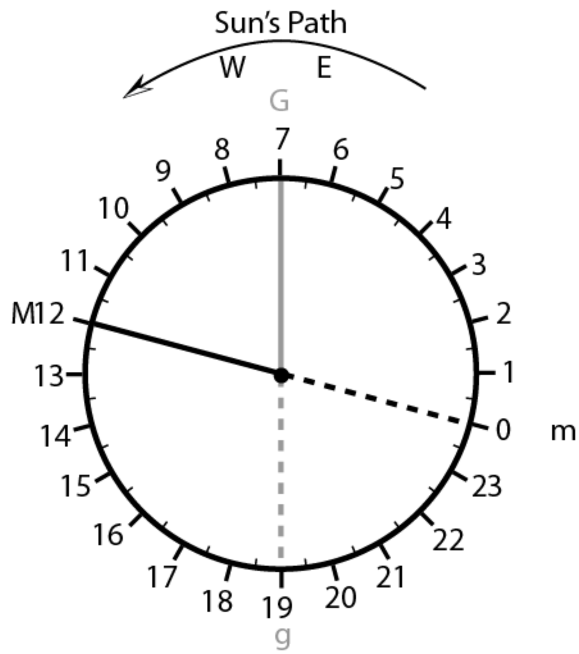
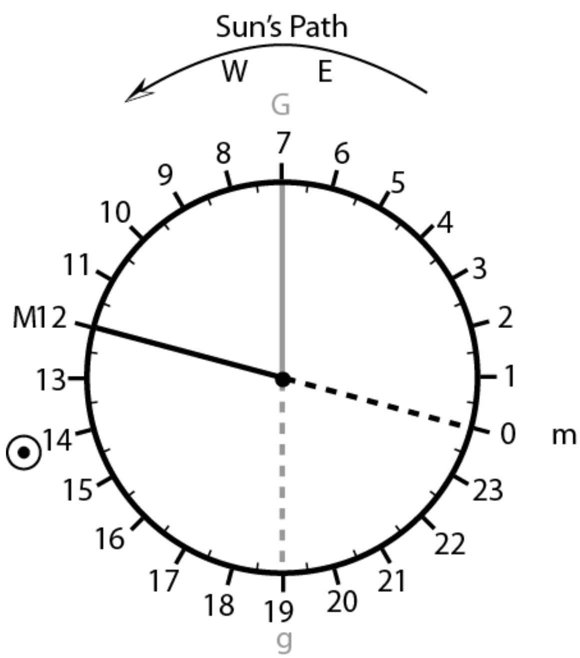


The diagram to the right is for a longitude of 075^0W and the Greenwich meridian branches have been dimmed. All the same definitions apply. 12 o'clock occurs when the Sun is at M. Midnight occurs when it is at m. The time difference between G and M is 5 hours and, as you already know, the longitude difference is 75^0.



The diagram to the left is identical to the one above except that the Sun's position has been added. Its angular difference from the local meridian is 30^0 or 2 hours. Therefore the local time at the observer's position is 2pm (14-00-00); pm means "post meridiem" which is Latin for passed midday. Think of it as meaning "Passed my Meridian".

Now you already know that to look up the Sun's data in the Nautical Almanac you need the time at Greenwich. Look at the next diagram.

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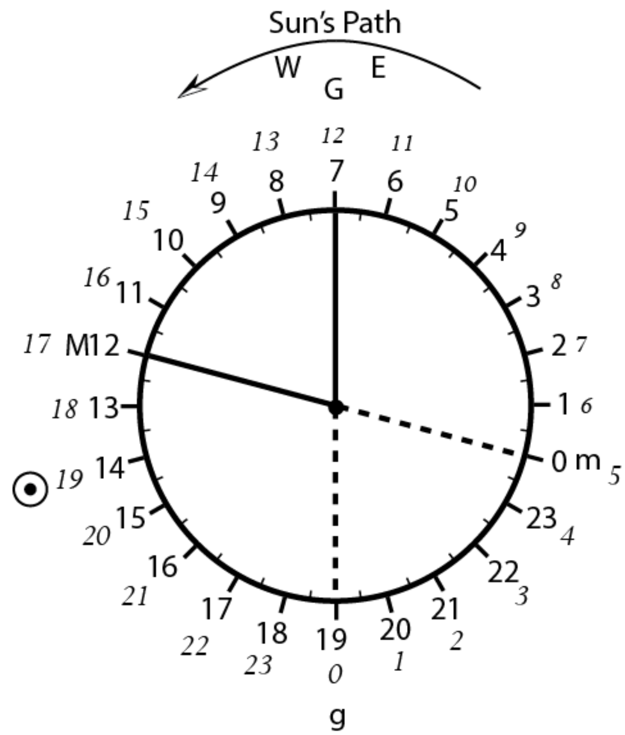
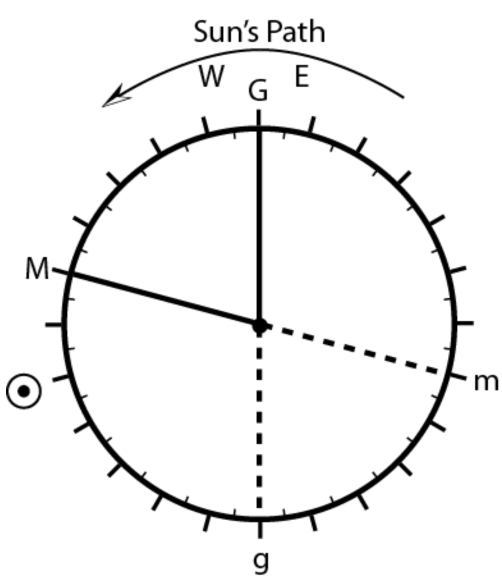


In this diagram both the local clock and the Greenwich clock are shown. The local clock is the inner numbers in this type face. *The Greenwich clock is the outer numbers in this typeface.*

In all instances the time difference between the observer's time and Greenwich time is 5 hours (75^0/15).

The data in the Nautical Almanac uses the time at Greenwich. Therefore in this example to look up the Sun's data in the Nautical Almanac you would go to the appropriate daily page and use 19-00-00 as the time. 19-00-00Z and 14-00-00E are equivalent. Z is the time zone suffix for Greenwich; E is the time zone suffix for 075^0W (see page 6-3).

It should be obvious that this is a very cluttered diagram. The clock face numbers are not really necessary. In all instances the time can be deduced by using the 24 hour system and count the hour (15^0) segments, following the Sun's path, from the lower branch starting at 0 or start at 12 and count up or down from the upper branch. Of course the branches to use would depend on whether you are interested in the observer's time (M or m) or the Greenwich time (G or g).



The above diagram has been "cleaned up" and is shown to the left.

It is more representative of a timing diagram that would be used in the practice of celestial navigation.

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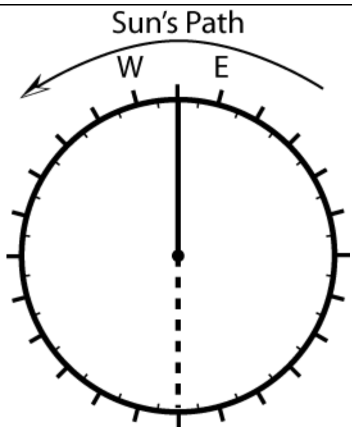
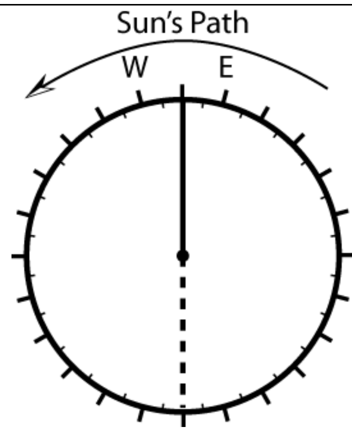
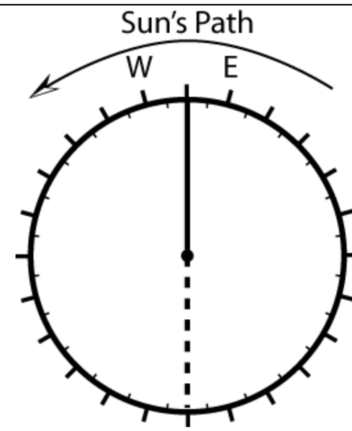
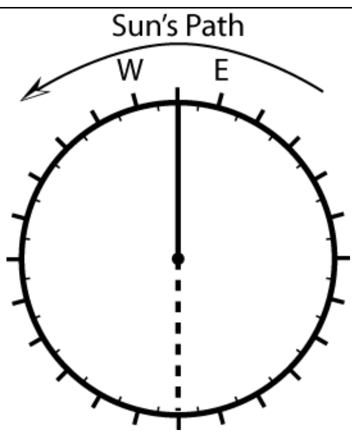
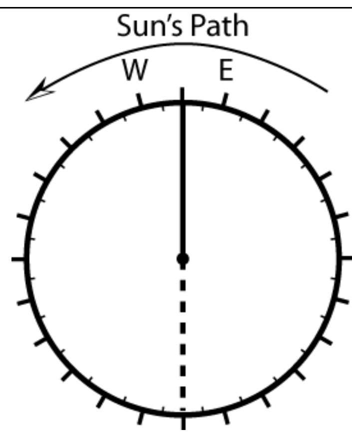
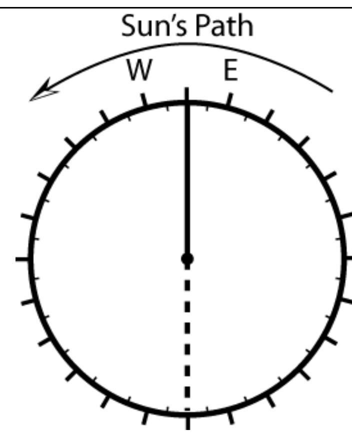
6.8.3. Timing Diagrams Exercise

Using the time diagrams from exercise 2 add the Sun at the local times indicated.

105° East 10am	090° West 3pm	060° East 6am
		

140° West 8pm	128° East 8am	025° West 1pm
		

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6.9. Date at Greenwich

There are three possible situations:

a. Local date same as Greenwich date

b. Local date one day behind Greenwich date

c. Local date one day ahead of Greenwich date

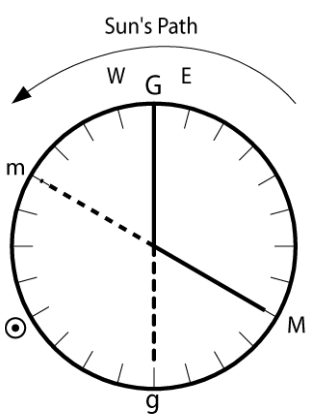
Any time the Sun is **between** the **lower branches** there is a **ONE-DAY** difference in the date.

If the Sun is between the lower branches and has **crossed the lower branch of the Greenwich meridian (g)** heading towards the **observers lower branch (m)** the Greenwich date is **one day ahead** of the local date. In other words it is after midnight at Greenwich but before midnight locally.

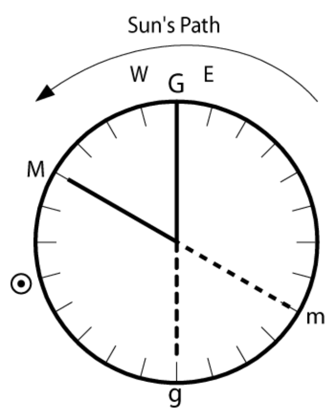
If the Sun is between the lower branches and has **crossed the observers lower branch (m)** heading towards the **lower branch of the Greenwich meridian (g)** the Greenwich date is **one day behind** the local date. In this case it is after midnight locally but not yet midnight at Greenwich.

Remember that whenever referring to the Nautical Almanac it is imperative that the correct Greenwich date be used.

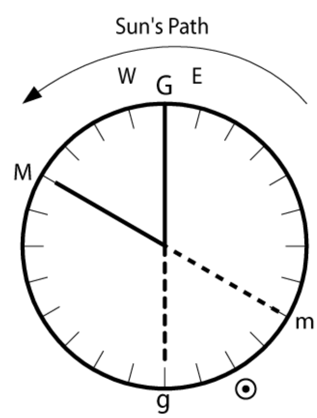
The following diagrams illustrate each case.



Greenwich date is one day behind the local date.



Greenwich date is the same as the local date.



Greenwich date is one day ahead of the local date.

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6.9.1. Greenwich Date Exercise

Refer to your answers for exercise 5-4 and using the above rules determine the date you would use in looking up data from the Nautical Almanac for each case.

6.9.2. Greenwich Time Exercise

a. The local time is 15 hours 34 minutes and 26 seconds on Feb 2nd. You are in the Pacific Ocean south of Japan near Hachijo-Jima at 33° 24.4'S 139° 34.6'E. What is the Greenwich time and date?

b. It is June 14th and you are in the Black sea south of Sochi 42° 35.0'N 039° 40.0'E; the local time is 0730. What is the Greenwich time and date?

c. The date is August 1st. The local time is 15 minutes before midnight. You are near Lajes (Terceira) in the Azores 38° 45.0'N 027° 05.0'W. What is the Greenwich time and date?

d. The date is 17th May. The local time is 02-30. You are south of Karachi in the Arabian Sea at position 22° 47.4'N 054° 45.7'E. What is the Greenwich time and date?

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6.10. Meridian Passage

When a celestial body is either due north or due south of your position it is on the same longitude or meridian as you are. This is termed Meridian Passage and the time this occurs is very important in celestial navigation as it is an easy way to establish your latitude, particularly meridian passage of the Sun. You will learn later that without using any sight reduction tables or complicated formulae you can establish your latitude easily from a "noon" sight of the Sun. This section focuses on how to determine the time of Meridian Passage; the sight reduction section will deal with how to get the latitude. The Sun is used as the example but the principle applies to all bodies.

Before you go on you must understand why "noon" has been put in quotation marks in the previous paragraph.

"Noon" is when the Sun is at its highest in the sky for that day; it is not necessarily 12 o'clock on your watch. Your watch is set to zone time so will indicate the same time over a band of longitude 15º wide. As you learned in previous paragraphs time is related to longitude. So the time the Sun will be at its highest on YOUR longitude depends on what YOUR longitude is. That's easy enough to deal with using the arc-time conversion tables in the Nautical Almanac.

However there is another variable you need to take into account. So far you have been working with a Sun that rotates about the Earth at a rate of 15º per hour. That is called the **Mean** Sun. The real Sun is sometimes a little faster or a little slower than this. This is referred to as the **Apparent** Sun. The difference between the Apparent Sun and the Mean Sun can be as much as 15 minutes. This difference is called the **Equation of Time**.

If you look at the bottom right hand corner of any daily page in the Nautical Almanac you will find the equation of time and the time of meridian passage of the Sun. Take look at the two extracts from the Nautical Almanac.

Day	SUN		
	Eqn. of Time		Mer.
	00^h	12^h	Pass.
d	m s	m s	h m
4	00 52	01 02	11 59
5	01 12	01 22	11 59
6	01 32	01 42	11 58

Fig 1

Day	SUN		
	Eqn. of Time		Mer.
	00^h	12^h	Pass.
d	m s	m s	h m
12	05 34	05 38	12 06
13	05 41	05 45	12 06
14	05 48	05 52	12 06

Fig 2

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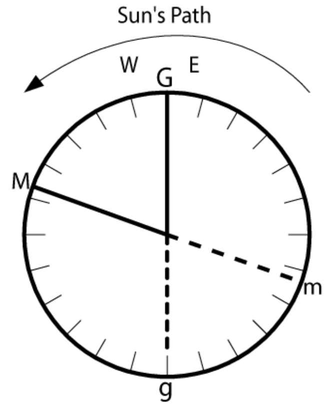
In Fig 1 the time of meridian passage is before 12:00 so the apparent (real) Sun arrives at the Greenwich meridian ahead of the noon of Mean Time. In Fig 2 the opposite occurs; the shading indicates negative. You use this information, in conjunction with your longitude, to determine the time of meridian passage for your location.

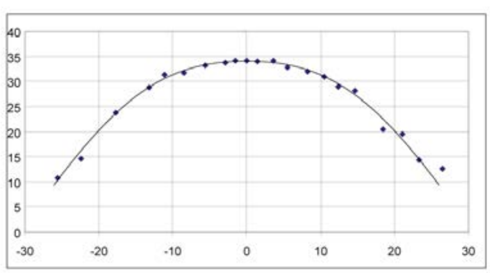
Here is a practical example to help clarify the concept.

Assume you want to calculate the time the Sun was due south on longitude 073º 48.2’W on 22 Feb 2007.

First look up the time of meridian passage of the Sun at Greenwich on 22 Feb and you find it to be 12:14. The center of the time zone is 075ºW and, assuming your watch was absolutely correct, the Sun would have been due south at 12:14 local time if you were on longitude 075ºW.

However you are not at the center of our time zone you are 1º 12’ east of it (075º - 073º48’); you can ignore the decimal parts of the minutes in this case. You do not need that level of precision for planning a noon sight. So using the arc to time table to convert this difference in longitude to a time you get 4 minutes 48 seconds. You can round this to 5 minutes because you will be planning to be ready to take the sight well ahead of time anyway. So because you are east of the central meridian of your time zone you will experience meridian passage 5 minutes earlier ie 12:09. It is easy to determine whether the time will be earlier or later by using a time diagram. Of course you will plan to be on deck several minutes ahead of 12:09 to start taking sights.





A good technique to use to determine the actual Sun’s altitude at “noon” is to take a series of sights and plot them as shown in the diagram (these are actual sightings). If you make sure you measure the angle when the Sun is at its highest point in the sky it must be local noon. You do not need accurate time because the Sun’s altitude changes very little either side of noon - it seems to hang in the sky for a couple of minutes. It can be seen that for a few minutes either side of local noon the angle changes very little. The duration of this “hang” depends on the time of the year and your latitude.

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6.10.1.Time of Meridian Passage Exercise

Calculate the time of local meridian passage to the nearest minute for each date and longitude in the table. Ignore DST.

Date	Meridian Passage Greenwich	Longitude	Time Zone Centre	Longitude difference (Angle)	Longitude difference (Time)	Meridian Passage Local
6 Aug 2007		123º 37.4’W				
19 Jul 2007		068º42.4’E				
20 Sep 2007		158º 37.4’E				
8 May 2007		175º 23.8’W				
12 Jun 2007		049º 58.6’W				
23 Feb 2007		007º 28.8’E				
21 Jun 2007		010º 32.6’W				

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6.11. Twilight

In the introduction you learned that to be able to use the sextant you need to be able to see the body AND the horizon. Obviously the horizon is clearly visible during daylight so if the Sun, Moon, or any of the planets are in view you can take sights. To take sights of the stars they must also be visible. Everyone knows that the stars are not visible during the day. They are visible at night but at night you cannot see the horizon so you cannot take sights. There is a period after sunset and before sunrise when the horizon and some of the stars are both visible. This is twilight. Morning twilight ends at sunrise and evening twilight starts at sunset.

OK you say but what about a night when the moon is bright; surely the horizon is visible. Using a moonlit horizon can lead to false fixes as moonlight gives a false horizon. It is possible but specialised techniques are required that will not be covered in this course.

By definition sunrise and sunset occur when the upper limb is just on the visible horizon. These times appear on the daily pages of the Nautical Almanac. Only data for the middle day is provided but there are tables that allow correction for the other days and also for different latitudes. For sight planning purposes only the correction for latitude is usually used; the correction for the days either side are not usually required.

There are in fact three “twilights”; civil, nautical, and astronomical.

Civil twilight is defined as the period between sunset (or sunrise) and when the centre of the Sun is 6º below the horizon.

Nautical twilight is defined as the period between the dark limit of civil twilight and when the centre of the Sun is 12º below the horizon.

Astronomical twilight is defined as the period between the dark limit of nautical twilight and the centre of the Sun being 18º below the horizon.

Only the times of civil and nautical twilight are given in the Nautical Almanac as these are the only times useful for taking sights. In fact the best time is the period when the Sun is between 3º and 9º below the horizon. The mid-point of this period is approximately the time of civil twilight.

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6.11.1. Times of Sunset, Sunrise, & Twilight

For sight planning purposes the following is accurate enough.

1. Look up the time from the daily page for the date required. Pay attention to the latitude. Select the latitude nearest to and **below** your latitude. If precise time is desired use the latitude correction tables in the Nautical Almanac page xxxii.
2. Adjust the time from the table to your longitude by adding or subtracting the difference between the centre longitude of your time zone and your longitude.

6.11.2. Moonrise and Moonset

The times of moonrise and moonset are also given on the daily pages in the same area as sunrise and sunset. A filled rectangle (■) indicates the Moon does not rise. An un-shaded rectangle (☐) indicates the Moon does not set. 4 slashes (////) indicate that twilight lasts all night.

The declination of the Moon changes much more rapidly than the Sun so data is given for the three days plus the following day. Again adjustments for latitude must be made if precision is required though it rarely is.

6.11.3. Time of Sunset, Sunrise, Twilight Exercise

1. For each of the following give the local time of sunrise and sunset to the nearest minute. Ignore Daylight Saving Time and all dates are 2007.

Date	Latitude	Longitude	Sunrise	Sunset
22 Feb	45ºN	75ºW		
9 May	47ºN	63ºW		
12 June	36ºS	24ºE		
23 June	36ºS	24ºW		
19 July	60ºN	18ºW		
18 Aug	62ºN	27ºE		
19 Sep	62ºN	27ºE		

2. Your position is 30^0 05.6’N 056^0 33.2’W. Assuming clear weather conditions at what time would you start taking star sights and how long would you expect to be able to take sights on the morning of June 12th and the evening of Feb 22nd?

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7. Hour Angles

7.1. Objective

By the end of this section you will understand the terms Greenwich Hour Angle (GHA), Local Hour Angle (LHA), Sidereal Hour Angle (SHA), the relationship between them, and their application in Celestial Navigation.

7.2. Introduction

In Coastal Navigation you became familiar with using longitude. In Celestial Navigation you will become used to using hour angles instead. Hour angles are synonymous with longitude but with a slight difference which is explained in the next section.

When using the Nautical Almanac and the tables to convert sextant angles into position data various Hour Angles are used. This section will introduce each of these hour angles and the relationship between them. Hour angles are also used in conjunction with the Star Finder when planning a celestial sight taking session. Hour angles are expressed in degrees and minutes of arc to one decimal place.

7.3. Greenwich hour Angle (GHA)

You will remember from Coastal Navigation that you use the Greenwich meridian as the starting point for measuring longitude and it is counted east and west up to 180°.

In Celestial Navigation you use Hour Angles instead of longitude. Hour angles are measured in degrees westward so you will realize that any **west longitude** is numerically the same when expressed as a **Greenwich hour angle** (GHA). To express an east longitude as a Greenwich hour angle it must be subtracted from 360°. That's the slight difference mentioned above.

The Nautical Almanac daily pages list, among much other data, the GHA's for the Sun, Moon, and Planets, that are used in celestial navigation. It also lists the GHA of Aries which is used when working with stars. In this section you will learn how to use the Nautical Almanac to determine the GHA for a celestial body at any time.

The celestial body that is most consistently available is the Sun. So it will be used for the next few examples. Please note that the same principles apply to any celestial body.

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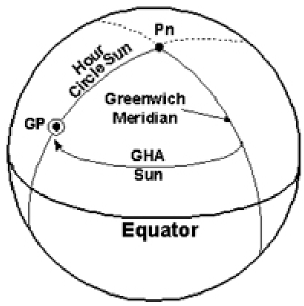
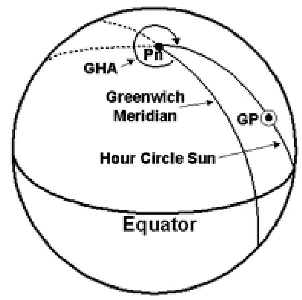


Figure 1 shows a view of the western hemisphere looking down slightly on the North Pole (Pn). The Sun's hour circle runs through western Ontario, longitude 90° West. The GHA of the Sun is 90°



In figure 2 the Sun's hour circle runs through Rome in central Italy at a longitude of 12° East or a GHA of 348° (360° - 12°). Notice that in both cases the GHA is measured from Greenwich in a westward direction.

7.4. GHA Sun from the Nautical Almanac

To look up the GHA for the Sun in the Nautical Almanac follow these steps.

1. Turn to the appropriate pair of pages for the relevant Greenwich date. Look at the page on the right hand side and select the appropriate date from the left hand column. There are three days per page so make sure you select the correct one. A common error is to just use the top part of the table which of course is the first day of the three.
2. Also in the left hand column find the "hours" component of the time.
3. From the next column (Sun) note the corresponding GHA degrees and minutes. Ignore the Dec (declination) for the moment; you will use it in a later section.
4. Turn to the "Increments and Corrections" pages in the back of the Nautical Almanac. Each page contains two tables. Look at the top to find the table which covers the appropriate "minutes" component of the time.
5. Having found the correct table look down the left hand column to find the "seconds" component of the time. From the next column (Sun Planets) note the corresponding degrees and minutes.
6. Add the increment found in step 5 to the angle from step 3. This is the GHA of the Sun for the specified time.

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7.4.1. Example

What is the GHA Sun at 13:45:16 on 8th May 2007?

13 hours	*15º 52.6'*
45 minutes 16 seconds	*11º 19.0'*
Total (GHA Sun)	*27º 11.6'*

7.5. GHA Aries, Planets, Moon

Use the exact same process to look up all the other GHA's in the Nautical Almanac. Just use the appropriate column from the daily pages and the Increments and Corrections tables. You will do this many times when you perform sight reductions in a later section.

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7.5.2. GHA Exercise

Using the 2007 Nautical Almanac extracts complete the table.

Greenwich Date	Greenwich Time	GHA Sun	GHA Aries	GHA Moon
May 7	06-00-00			
June 14	15-00-00			
Aug 6	06-23-00			
June 23	01-46-23			
Feb 21	05-28-12			
Sep 20	23-45-49			
May 7	20-15-17			
June 14	05-39-21			
Aug 6	06-24-49			
June 23	17-58-49			
Feb 21	05-55-43			
Sep 20	19-25-37			
May 9	20-15-17			
June 13	05-39-21			
Aug 5	06-24-49			
June 21	17-58-49			
Feb 23	05-55-43			
Sep 21	19-25-37			

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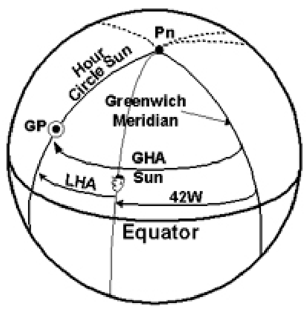
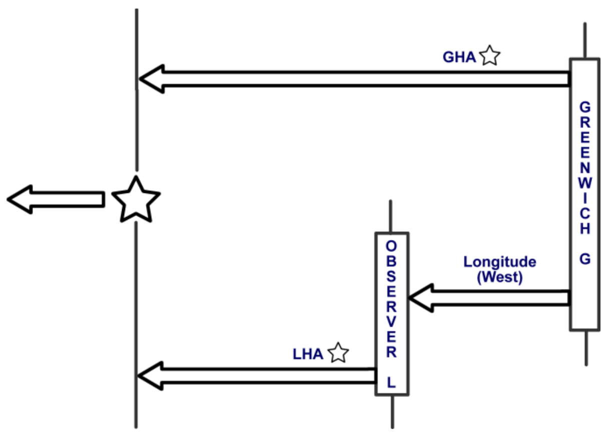
7.6. Local Hour Angle (LHA)

Now let's add an observer to the scenario as shown in following diagrams. The angle between the observer and the body's hour circle is called the **Local Hour Angle (LHA).** Again it is measured westward from the **observer's** meridian to the **body's** meridian. The LHA will be used in the sight reduction process.





When the longitude of the observer is in the western hemisphere:

LHA = GHA - Observer Longitude

In this figure the Sun has a GHA of 90° and the observer is in the middle of the Atlantic at longitude 042° W.

LHA = 90 – 42 = 48°

If the formula gives a negative result just add 360^{0} to get the answer. This will occur when the body is between the observer and Greenwich.

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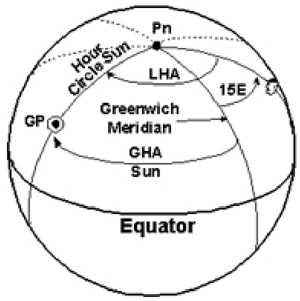

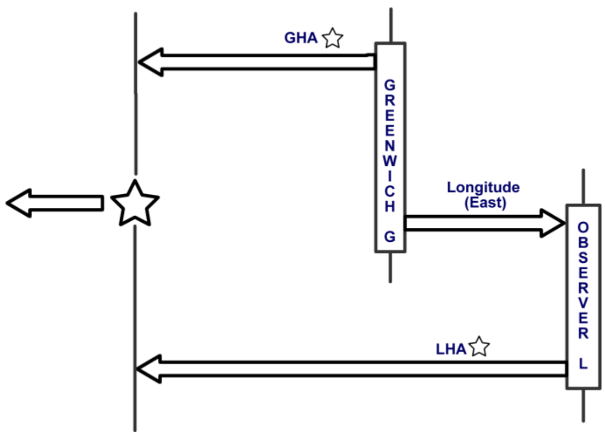

When the longitude of the observer is in the eastern hemisphere:

LHA = GHA + Observer Longitude

In this figure the Sun has a GHA of 90° and the observer is in the middle of the Mediterranean at longitude 018° E.

LHA = 90 + 18 = 108°

The general formula is:

$$\mathrm{LHA} = \mathrm{GHA} \begin{matrix} + \text{East Longitude} \\ - \text{West Longitude} \end{matrix}$$

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7.6.1. LHA Sun Exercise

Using the 2007 Nautical Almanac extracts complete the table.

Date	Time (GMT)	Longitude	LHA Sun
May 7	20-15-17	030° 05.2'W	
June 14	05-39-21	048° 07.8'E	
Aug 6	06-24-49	073° 45.8'W	
June 23	17-58-49	070 ° 34.9'W	
Feb 21	05-55-43	045° 17.6'E	
Sep 20	19-25-37	006° 57.4'W	
May 9	20-15-17	030° 05.2'W	
June 13	05-39-21	048° 07.8'E	
Aug 5	06-24-49	073° 45.8'W	
June 21	17-58-49	070 ° 34.9'W	
Feb 23	05-55-43	045° 17.6'E	
Sep 21	19-25-37	006° 57.4'W	

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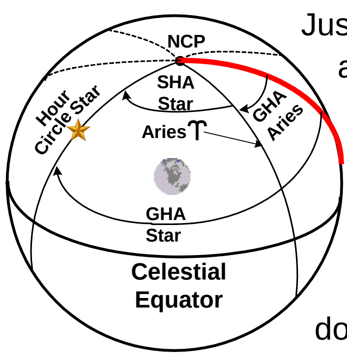
7.7. Sidereal Hour Angle (SHA)

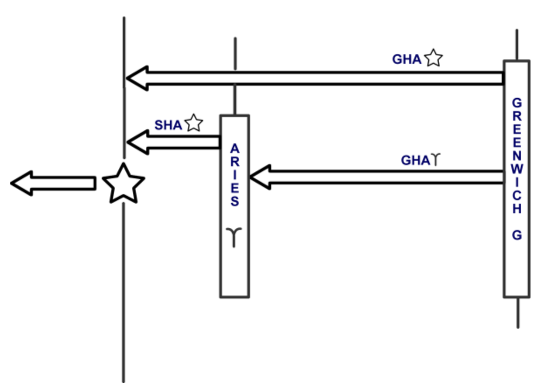
Before discussing **Sidereal Hour Angles** (SHA) let's take a quick look at the celestial sphere. Here again you are going to ignore most of what modern science tells us about the expanding universe, galaxies, etc. and of course Copernicus is still "wrong". The Earth is the center of everything and all the celestial bodies rotate around it☺!

Imagine the Earth is at the center of a giant ball – the celestial sphere. Painted on the inside surface of this ball are all the stars. The position of the stars relative to each other does not change. (In reality they do but the time period is measured in thousands of years and therefore not relevant as far as your navigation is concerned). The axis of rotation of the Earth and the axis of rotation of this ball are the same. In other words the celestial sphere has a North Celestial Pole (NCP) and a South Celestial Pole (SCP) exactly in line with their Earth bound counterparts. Similarly if you project outwards from the Earth's equator to the ball you will get the celestial equator. (Some texts refer to this as the equinoctal).



Just like the Greenwich meridian on Earth is an arbitrary line used as the starting point for longitude there is a similar line on the celestial sphere that is used as the reference for the stars. It is called the first point of Aries and is signified by a ram's horn ♈. It is defined by the point at which the Sun crosses the celestial equator traveling in a northerly direction (the vernal equinox). All the stars use this as their reference. If this was not done the Nautical Almanac would be thousands of pages long and totally unmanageable. From the diagrams (the heavy line is the Greenwich meridian) it will be evident that:

GHA Star = GHA Aries + SHA Star.



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The GHA of Aries and the SHAs of the 57 navigational stars are given in the Nautical Almanac daily pages.

Eg. To find the GHA of Altair on August 7th 2007 at 0100 GMT.

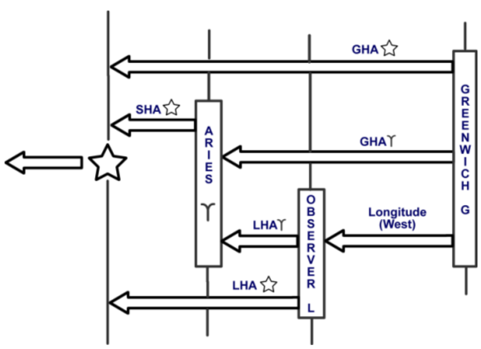
GHA Aries	330° 10.9’
SHA Altair	062° 12.3’
GHA Aries + SHA Altair =	392° 23.2’
GHA Altair	032° 23.2’

7.8. LHA Star

To find the LHA of a star you use exactly the same process already discussed.

$$LHA = GHA\,{}^{+\text{ East Longitude}}_{-\text{ West Longitude}}$$

7.9. Hour Angle Relationships Summary



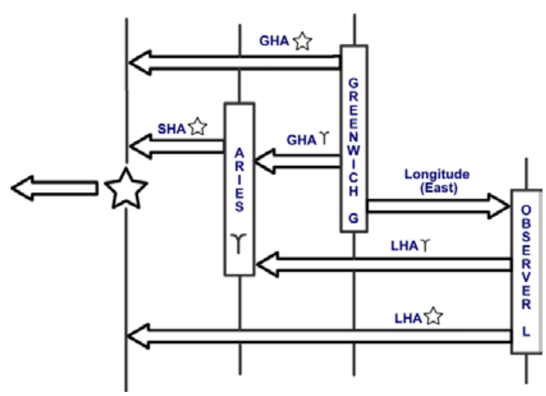
The diagram to the left shows all the relationships between the various hour angles for an observer located in the western hemisphere.

Remember hour angles are always measured in a westerly direction.

Observer with West Longitude

The diagram to the right shows all the relationships between the various hour angles for an observer located in the eastern hemisphere.

Remember hour angles are always measured in a westerly direction.



Observer with East Longitude

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7.9.1. LHA Stars Exercise

Using the 2007 Nautical Almanac extracts complete the table.

Date	Time (GMT)	Longitude	Star	LHA
May 7	20-15-17	030° 05.2'W	Aldebaran	
June 14	05-39-21	048° 07.8'E	Sirius	
Aug 6	06-24-49	073° 45.8'W	Alnilam	
June 23	17-58-49	070° 34.9'W	Rigel	
Feb 21	05-55-43	045° 17.6'E	Pollux	
Sep 20	19-25-37	006° 57.4'W	Procyon	
May 9	20-15-17	030° 05.2'W	Schedar	
June 13	05-39-21	048° 07.8'E	Deneb	
Aug 5	06-24-49	073° 45.8'W	Kochab	
June 21	17-58-49	070° 34.9'W	Spica	
Feb 23	05-55-43	045° 17.6'E	Arcturus	
Sep 21	19-25-37	006° 57.4'W	Dubhe	

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8. Celestial Bodies

8.1. Objective

In this section you will be introduced to the celestial bodies used for navigation – the Sun, the Moon, 4 Planets and some of the 57 stars, with guidelines to help you identify and find them in the sky.

8.2. Co-ordinate Systems

To define a position on the Earth's surface you use Latitude and Longitude. For celestial bodies you use **Declination** instead of **Latitude** and **Hour Angle** instead of **Longitude**. In the previous section you have learned how to determine the various hour angles. Remember that hour angles are synonymous with longitude except they are always measured in a westerly direction. Declination is measured in exactly the same way as Latitude i.e. it is an angle measured north or south of the celestial equator. The celestial equator is a projection of the Earth's equator onto the celestial sphere.

For example an object with Dec 45° 28'N and GHA 073° 45'would be directly over Trudeau airport – 45° 28'N 073° 45'W.

8.3. The Sun

The Sun is the most available and most reliable star. It appears every day and can be used even on a cloudy day as long as the cloud cover is not too thick.

> ***HHU Hint*** *If you can see shadows you can usually take sights using the Sun by selecting a combination of filters on the sextant.*

Its semi-diameter varies between 15.8' in July to 16.3' in January due to the Sun being closer to the Earth in January than July (surprise surprise!). Semi-diameter is important because when you use the sextant to take sights it is either the upper or lower edge, or limb as it is known, that you bring into line with the horizon. The solution to the spherical triangles provided in the tables is based on measurements from the centre of the Earth to the centre of the Sun. When you take sextant sights you measure from the surface of the Earth to the edge of the Sun. The necessary corrections are made using tables from the Nautical Almanac.

The Sun's declination varies through the year from 23° 26.4'N to 23° 26.4'S. These correspond to very significant latitudes. They are the Tropic of Cancer and the Tropic of Capricorn respectively. If you are sailing at latitudes higher than 23°26.4' the Sun will always be due north or south at the time of meridian passage depending on the hemisphere you are in and you will never have the sun directly overhead.

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8.4. Equinox

- Occurs when the Sun is directly over the equator.
- A time at which the days and nights are the same length around the world.
- Occurs around March 21 and September 21
- Is either vernal (in the spring) or autumnal (in the fall).

8.5. Solstice

- Occurs when the Sun is directly above the Tropic of Cancer (Summer Solstice) and the Tropic of Capricorn (Winter Solstice).
- A time at which either the day or night is the longest it will be during the year.
- Occurs around June 21 and December 20
- Will allow one pole to have 24 hours of daylight, while the other pole has a 24-hour night.

8.6. Stars

The list of the 57 Navigation Stars can be found in the Nautical Almanac in two places. There is a detachable coloured page that can be used as a bookmark for the daily pages in use. There is also an index page towards the back of the almanac as well as star charts for both hemispheres.

Ynot Sailing has developed a series of online learning aids to help you learn the major constellations and prepare you for the exam.

> ***Hint**. You do not need to remember all the stars. In fact you do not need to remember ANY of the stars to be able to successfully navigate. However you do need to know some to pass the CYA exam and it is helpful to know the major ones.*

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8.7. Planets

Venus, Mars, Jupiter, and Saturn are the only planets used for navigation purposes. The word planet originates from a Greek word meaning wanderer. Unlike the other celestial bodies that follow orderly paths across the heavens the planets seem, at first glance, to be erratic in their movement. Again you do not need to be concerned too much with why this is so. The entire math has been done for you and tabulated in the Nautical Almanac. The data for the planets can be found on the daily pages.

Venus is the brightest planet and when it appears it is quite often referred to as the morning or evening star. Venus can sometimes be used during the day to get a fix along with the Sun if you know where to find it. Although not visible to the naked eye it can be found with the sextant telescope.

8.8. Moon

Easily recognizable but not always available. It orbits the Earth on a 29½ day cycle. Occasionally both it and the Sun will be in view and at suitable angles to get a good daytime two body fix.

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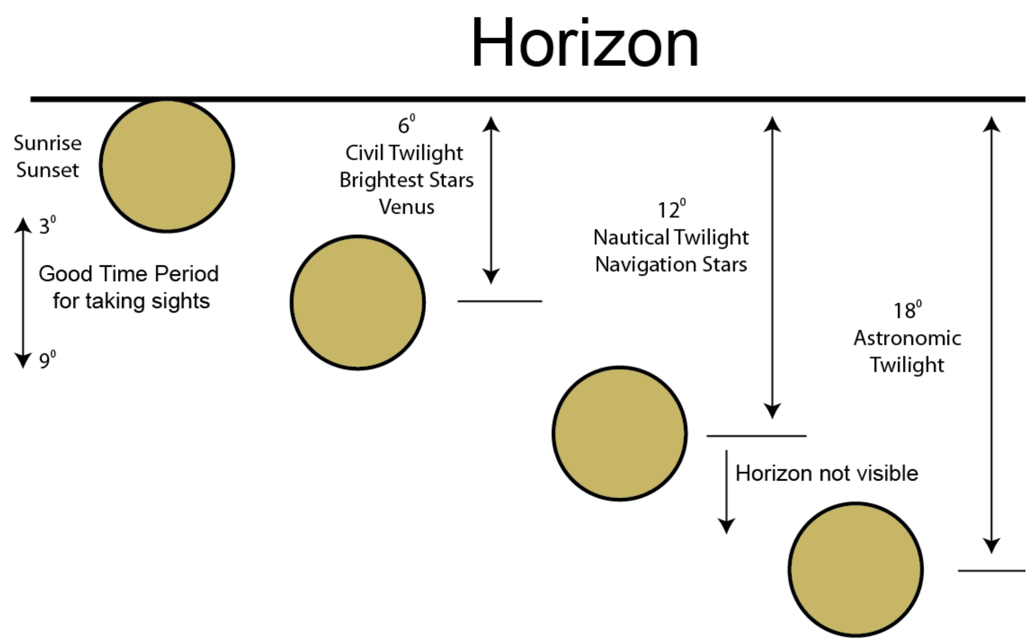
9 Sight Planning

Twilights and Sight Planning



Sight Planning

Use the star finder or HO 249 to identify the best set of stars to use. The best time period for taking sights is when the centre of the Sun is between 3 and 9 degrees below the horizon.

Morning Sights

Use the Nautical Almanac to determine the times of the twilights and sunrise making adjustments for latitude. Plan to be on deck at the time of nautical twilight when the horizon will just start to become visible. If Venus is above the horizon and not too close to the sun it will be visible even after sunrise. All the stars except the very brightest will be too dim to use when the centre of the Sun is within 3^0 of the horizon. The stars to the west will be usable longer than those to the east.

Evening Sights

Use the Nautical Almanac to determine the times of the twilights and sunset making adjustments for latitude. Plan to be on deck at sunset. The stars in the east will be the

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first to become visible so plan on taking these early in your sight taking session. The horizon will be usable until the nautical twilight.

The ideal situation to obtain a 3 body fix would be to have a completely cloudless sky, a clearly discernible horizon, little wave action so the boat is stable, and three easily visible bodies at altitudes between 30º and 70º spaced 120 º apart in azimuth.

Obviously the navigator has no control over the weather conditions. The helmsman, however, may be able to temporarily steer a different course to put the boat on a more stable point of sail.

The prudent navigator will plan the sight taking session well ahead of time to identify the best time and the most likely bodies (usually no more than 7 or 8) that would give acceptable cut angles when the LOPs are plotted. The data needed are:

- DR position
- Twilight times
- The name of the body
- The azimuth
- The altitude
- Magnitude

Although it is not essential to note the magnitude of the star on the planning sheet it is another factor that would be considered when selecting suitable bodies and is useful in helping to identify the body in the sky. The magnitude can be found on the Nautical Almanac page marker and also on the Index to Selected stars page towards the back of the Nautical Almanac.

During the day the sky is too bright to be able to see the stars but of course the horizon is clearly discernible. With pre-computation it is sometimes possible to sight the Moon and / or Venus using a suitable sextant telescope even though they may not be visible to the naked eye because of the low contrast to the sky.

At the time given for civil twilight some of the brightest stars may be visible as is the horizon; at nautical twilight it is too dark to be able to discern a useable horizon. Consequently the best time for taking star sights is between the two twilights starting at the time of nautical twilight in the morning and at civil twilight in the evening. For sight planning purposes use the time of nautical twilight for the morning session and civil for the evening session.

A sight planning form is included with your course material but of course you could always design one for yourself.

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The times given in the Nautical Almanac can be considered to be LMT and are given at various latitudes for the middle day of the three days shown on the daily pages. The times change very little from day to day so the middle day times can be used for all three days. Correction for latitude can be done using a table in the back of the Nautical Almanac and correction for longitude is done in the normal manner. The sight planning form has been designed for use with this table. For sight planning purposes times to the nearest minute are accurate enough.

Times **MUST** be converted to **GMT** before any data are looked up on the Nautical Almanac daily pages.

9.1 Sight Planning Tools

The most commonly used tools to plan sight sessions are the Star Finder 2102-D and Volume 1 of H.O 249. Both will give altitude and azimuth of the stars. With the 2102-D you select your stars; H.O. 249 selects the best seven for you and indicates which three give the best cut angles for a three body fix. H.O. 249 only gives stars; 2102-D can be used for all celestial bodies for which data are available in the Nautical Almanac.

There is also a variety of programmable calculators and of course computer programs that can be used for sight planning purposes.

9.2 Practicalities

Pre-computing the altitudes and bearings of the stars makes the sight taking session much easier and quicker. Pre-computation allows you to take more sights in the limited time available as you do not need to “bring down” each body from altitude to the horizon; a time consuming task. It also has the effect of increasing the time available for taking sights because it allows for sighting bodies not visible to the naked eye due to low contrast. In these conditions the horizon is clearly visible so the effective time span is increased as is also the accuracy of the sight. Several sights can be taken on each of the stars to increase the accuracy of the fix using averaging techniques.

Having selected your stars just set your sextant to the indicated altitude, scan the horizon in the general direction given and, assuming a cloudless sky, the star will appear in the telescope or sight tube. Bring it down to the horizon in the usual way. Using this technique it is easy to get multiple sights on a star less than one minute apart.

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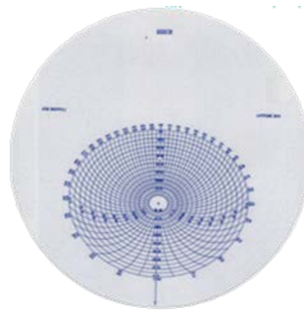
9.3 The Star Finder 2102-D

The Star Finder is used to determine the altitudes and azimuths of stars, the Moon, and planets. It does not show the stars as they appear in the sky. Do not try to compare these layouts with the actual sky.

Star Base North Side



Altitude / Azimuth Template

The Star Finder 2102-D comprises one dual sided star base (white), nine altitude / azimuth templates (blue) and a meridian angle declination template (red).

9.4 Star Sight Planning

Here are step-by-step instructions for finding which stars are available for a sight.

1. Select the appropriate side of the white star base (N or S) depending on which hemisphere you are in.
2. Select and install the appropriate blue altitude / azimuth template for the latitude nearest to your position. Make sure you use the correct side (N or S)
3. Determine the LHA ♈ and align the pointer on the blue template with this angle on the star base. (Reminder LHA = GHA + E/-W Longitude).
4. Read the approximate altitudes and azimuths of the stars marked on the star base where they show through onto the blue lines on the altitude / azimuth template. The criteria to be used in selecting stars is cut angle (as close to 120º as possible), altitude (ideally between 30º and 70º) and magnitude (lower is better). Selecting 6 stars at 60º azimuth separations gives lots of opportunities for good cut angles.
5. The star finder uses 3 different size symbols to indicate magnitude grouping; the larger symbol representing the brightest stars.
6. Stars that appear outside the outer blue line are below the horizon and consequently not visible.

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9.5 Planet Sight Planning

The relative positions of the stars are, to all practical purposes, fixed. That allows them to be printed on the star base. This is not the case for the planets whose positions vary relative to the stars and indeed themselves. Consequently they need to be marked on the star base every few days. Here are step-by-step instructions for adding the planets and determining their availability for sights.

1. Select the appropriate side of the white star base (N or S) depending on which hemisphere you are in.
2. Select and install the red template, south side up.
3. Determine the Right Ascension (RA) for each of the planets. The easiest way to do this is to look up the SHA of each planet in the bottom right hand corner of the left hand daily page in the almanac and subtract it from 360°.

   RA = 360º - SHA

   An alternate method is RA = GHA ♈ - GHA(Planet)
4. Look up the declination for each planet from the middle day of the three days. The time does not matter as the declination changes very slowly.
5. Set the 0° arrow on the red disk to each of the planets' RA's in turn on the rim of the white star base. Using the scale on the cutout in the disc and a pencil, mark the planet on the star base paying attention to whether the declination is North or South.
6. Replace the red disc with the appropriate blue disc and set it up and use it in exactly the same way as described for stars.

9.6 Moon Sight Planning

It is sometimes advantageous to be able to predict whether the Moon will be in a suitable position to be used in combination with other bodies for a fix. The Moon can be added to the star base in exactly the same way as the planets but needs to be done more frequently as the moon moves much quicker than the planets.

The outer rim must be set to the Right Ascension (RA).

RA = (360º - SHA Moon)
SHA (Moon) = GHA Moon – GHA Aries
Therefore RA = GHA Aries – GHA Moon

Declinations of the Moon are listed for each hour.
The Red template is replaced by the appropriate blue template and used in exactly the same way described above for the stars to mark the azimuth and altitude of the Moon.

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9.7 Sun Sight Planning

The Sun can be added to the star finder in exactly the same way. This can be useful in determining the time interval to wait when using the Sun-run-Sun technique which will be covered in a later section. It is also useful for determining if (and when) there is an opportunity during the day for a Sun / Moon fix.

Remember that hour angles are expressed in degrees but could equally well be expressed as a time. The out rim of the star finder disk is graduated in degrees but you could add times in pencil if you wish.

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9.8 H.O. 249 Volume 1.

The pages in H.O. 249 volume 1 are arranged by latitude with, in most cases, two pages per latitude. On each page there are two columns with the left hand column in each case being LHA ♈ and the remaining seven columns giving the calculated height (Hc) and azimuth (Zn) for the seven selected stars. Several factors including azimuth, magnitude and altitude, were used in selecting the seven stars and in each case the three most suitable for a three body fix are indicated by an ◆. The names in CAPITAL letters are the brighter stars.

To plan your sight taking session is as easy as picking the appropriate page for your DR latitude, calculating the LHA ♈ based on the time and your DR longitude and then reading the data from the table.

Here is an example.

DR 43º 02.1'N

045º 44.8'W

18th August 2007

Nautical Twilight

07-03 GMT.

GHA ♈ 072º 01.3'

LHA ♈ 026º 16.5'

LAT 43°N

LHA ♈	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn
	◆CAPELLA		ALDEBARAN		◆Diphda		FOMALHAUT		ALTAIR		◆VEGA		Kochab	
0	35 46	057	26 21	092	28 14	168	16 03	194	26 16	257	31 18	296	30 35	348
1	36 23	058	27 05	092	28 22	169	15 52	195	25 34	258	30 39	296	30 26	348
2	37 00	058	27 49	093	28 30	170	15 41	196	24 51	259	30 00	297	30 16	348
3	37 37	058	28 33	094	28 37	171	15 29	197	24 08	259	29 21	297	30 07	348
4	38 15	059	29 16	094	28 44	172	15 16	197	23 24	260	28 42	298	29 59	349
5	38 52	059	30 00	095	28 49	173	15 02	198	22 41	261	28 03	298	29 50	349
6	39 30	060	30 44	096	28 54	175	14 48	199	21 58	261	27 24	299	29 42	349
7	40 08	060	31 27	097	28 57	176	14 33	200	21 14	262	26 46	299	29 34	349
8	40 46	060	32 11	097	29 00	177	14 18	201	20 31	263	26 08	300	29 26	350
9	41 24	061	32 54	098	29 02	178	14 02	202	19 47	264	25 30	300	29 18	350
10	42 03	061	33 38	099	29 04	179	13 46	203	19 04	264	24 52	301	29 10	350
11	42 41	061	34 21	100	29 04	180	13 28	203	18 20	265	24 14	301	29 03	351
12	43 20	062	35 04	100	29 04	181	13 11	204	17 36	266	23 37	302	28 56	351
13	43 59	062	35 47	101	29 02	182	12 52	205	16 52	266	23 00	302	28 49	351
14	44 37	062	36 30	102	29 00	183	12 33	206	16 09	267	22 23	303	28 42	351
	◆CAPELLA		BETELGEUSE		RIGEL		◆Diphda		Enif		◆DENEB		Kochab	
15	45 16	063	16 47	096	12 53	114	28 57	184	36 17	247	44 54	296	28 36	352
16	45 56	063	17 30	096	13 33	115	28 54	185	35 36	248	44 15	297	28 30	352
17	46 35	064	18 14	097	14 12	116	28 49	186	34 56	249	43 35	297	28 24	352
18	47 14	064	18 58	098	14 52	117	28 44	188	34 15	250	42 56	297	28 18	353
19	47 54	064	19 41	098	15 31	117	28 38	189	33 33	250	42 18	298	28 12	353
20	48 33	065	20 24	099	16 10	118	28 31	190	32 52	251	41 39	298	28 07	353
21	49 13	065	21 08	100	16 48	119	28 23	191	32 10	252	41 00	299	28 02	353
22	49 53	065	21 51	101	17 26	120	28 14	192	31 28	253	40 22	299	27 57	354
23	50 32	065	22 34	101	18 04	121	28 05	193	30 46	254	39 43	299	27 52	354
24	51 12	066	23 17	102	18 42	121	27 55	194	30 04	254	39 05	300	27 48	354
25	51 52	066	24 00	103	19 19	122	27 44	195	29 22	255	38 27	300	27 43	355
26	52 33	066	24 42	104	19 56	123	27 32	196	28 39	256	37 49	300	27 39	355
27	53 13	067	25 25	104	20 33	124	27 19	197	27 57	257	37 11	301	27 36	355
28	53 53	067	26 08	105	21 09	125	27 06	198	27 14	258	36 34	301	27 32	356
29	54 34	067	26 50	106	21 45	126	26 52	199	26 31	258	35 56	302	27 29	356

See the diagram for the selected stars. They are arranged in order of azimuth.

They are CAPELLA, BETELGEUSE, RIGEL, Diphda, Enif, DENEB, and Kochab, with CAPELLA, Diphda, and DENEB being the most suitable for a three body fix.

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9.9 Star Finder Exercises

9.9.1 Exercise 1

a) Using the data from the above example, a sight planning sheet, and a star finder compare the altitudes and azimuths to the selection from H.O.249.

b) Would have chosen a different set of stars? If so explain why.

c) Optional for the math wizard with a scientific calculator.

Using the formulae given in the appendices, calculate the altitude (Hc) and Azimuth (Zn) and compare the results to the H.O.249 and star finder answers.

9.9.2 Exercise 2

Your DR position on May 9th 2007 is 46º 28.9'N 075º 16.9'E. Compile sight planning sheets for the morning and evening sight taking sessions. Choose what you believe to be the 7 best stars. In each time period indicate which three will give the best cut angle for a three body fix. Be prepared to justify your choices.

Hint: Prepare a timing diagram.

Use a star finder for this exercise.

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10Sight Reduction

10.1 Overview

There are several ways to determine your position using celestial navigation. All of them follow the same basic process.

1. Measure the vertical angle to the body (Hs) and record the precise time to the second at which the angle measurement was taken.
2. Add a few corrections to Hs to find Ho (height observed).
3. Calculate Hc (height calculated) based on an assumed position.
4. Use the difference between Hc and Ho to plot your celestial LOP.
5. Repeat for another body to get an intersecting LOP
6. Where the LOPs intersect you have a fix.

10.2 Sight Reduction Methods

The 5 common methods are:

- NAO
- H.O 211 (Ageton)
- H.O 229
- H.O 249
- Calculator / Computer

Here is a brief overview of each of these methods.

10.2.1 NAO

This method has the advantage of not needing any additional documents. The NAO sight reduction table is included in the Nautical Almanac which, as you already know, is essential for all methods of sight reduction. The disadvantage is that the tables must be entered twice for each sight to be reduced.

This method will be taught during the course.

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10.2.2 H.O 211 (Ageton)

This method uses a similar approach to the NAO method described above. However it is a more complex set of tables to use and it is easy to make errors.

This method will not be taught during the class but the tables and an explanation of their use are on the course CD.

10.2.3 H.O 229

This is the standard set of tables designed for marine navigation. Although there are 6 volumes in a set, each covering 15º of latitude, only those pertaining to the latitudes anticipated need be obtained. Their tabular data, being purely mathematical results, never go out of date. The latitudes listed for the volumes work for both the northern or southern hemispheres. A complete set in pdf format is included on the course CD.

This method will be not taught during the course but will be very easy to use after learning the H.O. 249 method.

10.2.4 H.O 249

These tables were designed for air navigation where weight and space were at a premium; however, they are also very popular with sailors due to the reduced size and weight. The accuracy is quite sufficient for navigation and Vol. 1 offers a speedy way to compute stars. The way the data from 6 volumes of H.O 229 were reduced into this 3 volume set is by having volumes 2 & 3 cover all latitudes, but working only for declinations from 0° to 29° north or south. This covers the Sun, Moon, planets, and 30 of the 57 stars whose declinations fall into this range. There is also a slight reduction in accuracy but this is not significant for small boat navigation. Volume 1 contains some stars (whose declinations may be more than 29°) that are pre-selected for optimum viewing and direction. This volume is applicable for an 8 year period, centered on its epoch date. The only drawback to this arrangement is that it is possible that a star may be observed that is not one of the pre-selected ones, and whose declination is more than 29° north or south. This star, if observed on some unlikely occasion, say through a break in the overcast, could not be computed using the H.O 249 tables. Nevertheless this remains the most popular tabular system in use. A complete set in pdf format is included on the course CD. Volumes 2 and 3 are perpetual.

This method will be taught during the course.

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10.2.5 Calculator/Computer

There are a variety of software programs that will perform the sight reduction for you. There are also some calculators pre-programmed to do this or you can enter the data into any calculator having trig functions. It is strongly recommended that you know how to reduce sights using one of the tabular methods before relying on any electronic device.

The process, formulae, and recommendations for suitable calculators are included in the appendices.

10.3 The 4 H's

When dealing with angles to celestial bodies and sight reduction there are 4 H's that we must deal with.

- Hs – (Height Sextant). The angle measured with the sextant between the celestial body and the observer's horizon. This is the starting point for several corrections that need to be applied. It is simply the angle read directly from the sextant arm.
- Ha – (Height Apparent). Hs corrected for Index Error (covered in an earlier section) and Dip (see next paragraph). To get the Ha read the sextant angle (Hs) apply the **index correction** (see earlier section) and then **subtract** the dip that you look up in the Nautical Almanac.
- Ho – (Height Observed). Ha corrected for a bunch of stuff explained later.
- Hc – (Height Calculated). The calculated altitude of a body based on an assumed position. Again to be explained later.

✶ *HHU Hint - Don't worry about remembering any of this. There are places on the sight reduction forms with reminders. Just be aware that there are corrections to be made and a sequence in which they must be done.*

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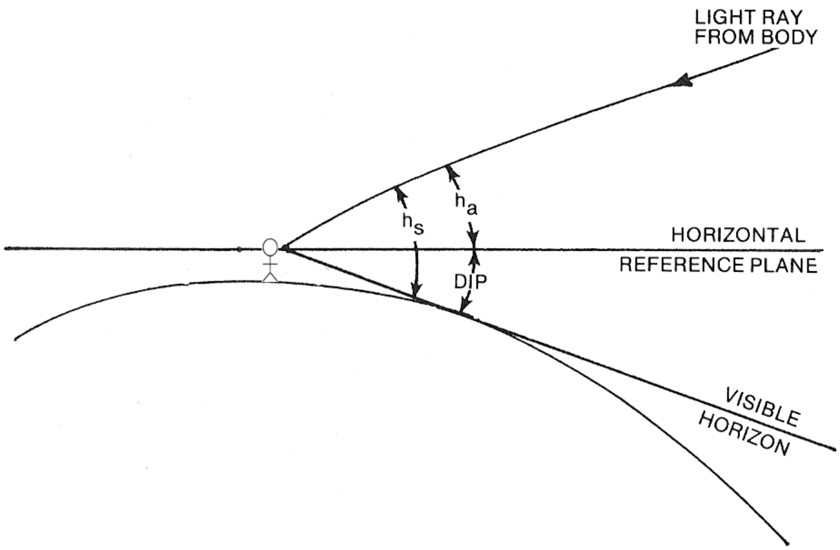
10.4 Dip



As previously mentioned the sextant measures angles between the celestial body and the horizon – specifically the visible horizon. We need to know the angles referenced to the horizon tangential to the earth at the observers position.

One glance at the diagram will show the relationship. Obviously the higher the observer's eye the greater will be the dip angle. There are formulae to calculate the dip correction but again the Nautical Almanac comes to the rescue with a look up table. It's on the same detachable page as the altitude correction tables and reproduced in the Nautical Almanac extracts in the appendices.

This is a critical table which means that one correction is given for a range of values. You always select the upper value (physically NOT numerically higher) from the table.

For example if your height of eye is 36.3 feet the correction is –5.8'.

HHU Hint - Dip is always subtracted from the sextant reading.

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10.4.2 Dip Exercise

Complete the table using the table found on the detachable page marker of the Nautical Almanac.

Ht of Eye	Dip
6 ft	
9 ft	
8 ft 6”	
10 ft 6”	
3.8m	
2.9m	

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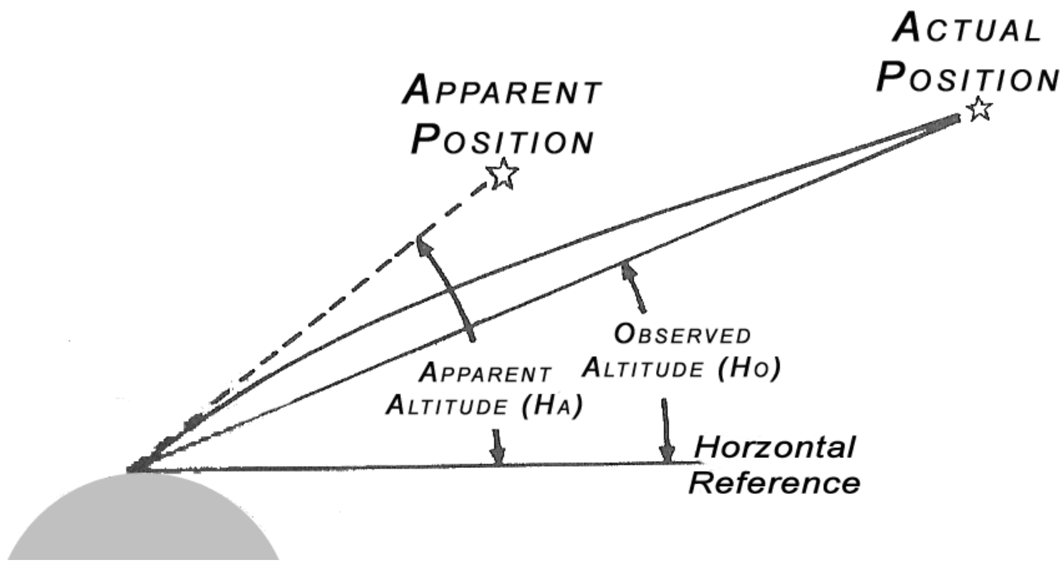
10.5 Ho – (Height Observed)



Light travels in a straight line in a vacuum but when it hits the earth's atmosphere it bends just like when you put a stick in water. Consequently we need to correct for the bend. The amount of bend varies depending on the amount of air, which in turn depends on the angle to the body; the higher the angle, the lower the bend. This adjustment is called **Altitude Correction** and can be found in tables in the Nautical Almanac. For the Sun, Stars and Planets it is also on the pullout page used as a bookmark along with the dip table. The altitude correction for the Moon is on other tables in the back of the Nautical Almanac.

Where possible avoid using altitudes less than 15º. In fact if you use an altitude of 10º or less you must also record the air temperature and barometric pressure and apply additional corrections based on these data.

By observation the apparent altitude will always be bigger than the observed altitude. So you would expect that the correction to be applied would always be negative but this is only true for the planets and the stars. The explanation is that the altitude correction tables for the Sun also include other correction factors, such as semi-diameter, and therefore care must be taken to apply the sign (+ or –) as given in the table. Likewise the altitude correction table for the Moon also includes other factors and the value from the table should always be added.

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Let’s take a look at the Sextant section of the sight reduction work sheet.

Sextant	
Hs	______°______’
IC (on - / off +)	______’
Ht of eye ___ (m/ft)	
Dip (-)	______’
Ha	______°______’
Altitude Corrections	
Alt. Corr	______’
UL Moon	-30’
HP Moon ( )	______’
Addit. Planet	______’
Total ( )	______’
Ho	______°______’

Transfer the readings from your sight worksheet. Hs is the sextant angle

IC is the same magnitude as the Index Error but opposite sign.

Height of Eye; use either feet or meters but be consistent.

Enter the dip value from the table.

Ha = Hs ± IC – Dip

Altitude corrections from the Nautical Almanac table; use Ha as the entry value.

UL & HP are only used when taking sights of the Moon. Ignore for all other sights.

Additional correction is only applicable to planets.

Add up all the corrections

Ho = Ha ± Total

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Here's a completed example using the Sun's lower limb on a date in August.

Sextant	
Hs	43º 34.8'
IC (on - / off +)	+ 1.4'
Ht of eye 10 (m/ft)	
Dip (-)	-3.1'
Ha	43º 33.1'
Altitude Corrections	
Alt. Corr	+ 15.0'
UL Moon	~~-30'~~
HP Moon ( )	________'
Addit. Planet	________'
Total ( )	+15.0'
Ho	43º 48.1'

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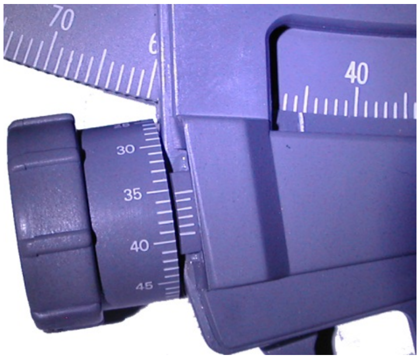
10.5.1 Height Observed (Ho) Exercise

Using the photographs and the information given determine Ha and Ho in each case. The upper photo of each pair shows the Index Error.

1

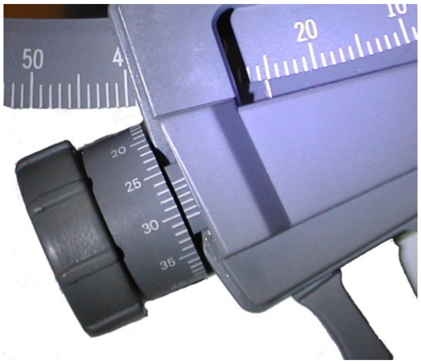


Height of Eye 10 ft

Star

Sextant	
Hs	______° ______'
IC (on - / off +)	______'
Ht of eye ___ (m/ft)	
Dip (-)	_______'
Ha	______° ______'
Altitude Corrections	
Alt. Corr	_______'
UL Moon	-30'
HP Moon ( )	_______'
Addit. Planet	_______'
Total ( )	_______'
Ho	_____° _______'

2



Height of Eye 9 ft

Star

Sextant	
Hs	______° ______'
IC (on - / off +)	______'
Ht of eye ___ (m/ft)	
Dip (-)	_______'
Ha	______° ______'
Altitude Corrections	
Alt. Corr	_______'
UL Moon	-30'
HP Moon ( )	_______'
Addit. Planet	_______'
Total ( )	_______'
Ho	_____° _______'

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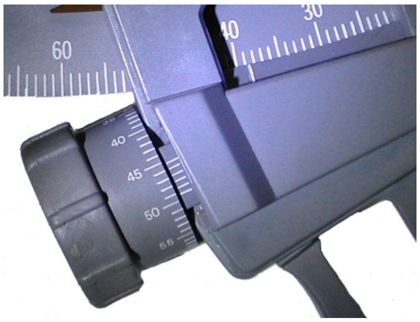
3



Height of Eye 11 ft

Sun (LL)

Aug 7th

Sextant

Hs ______° ______'
IC (on - / off +) ______'
Ht of eye ___ (m/ft)
Dip (-) ______'

Ha ______° ______'

Altitude Corrections

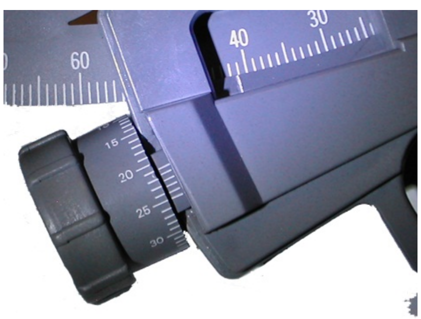
Alt. Corr ______'
UL Moon -30'
HP Moon ( ) ______'

Addit. Planet ______'

Total ( ) ______'

Ho ______° ______'

4



Height of Eye 15 ft

Star

Sextant

Hs ______° ______'
IC (on - / off +) ______'
Ht of eye ___ (m/ft)
Dip (-) ______'

Ha ______° ______'

Altitude Corrections

Alt. Corr ______'
UL Moon -30'
HP Moon ( ) ______'

Addit. Planet ______'

Total ( ) ______'

Ho ______° ______'

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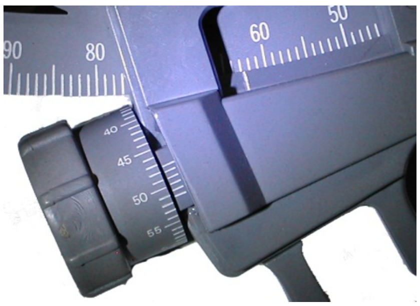
5



Height of Eye 14 ft

Sun (UL)

March 1st

Sextant	
Hs	______° ______'
IC (on - / off +)	______'
Ht of eye ___ (m/ft)	
Dip (-)	_______'
Ha	______° ______'
Altitude Corrections	
Alt. Corr	_______'
UL Moon	-30'
HP Moon ( )	_______'
Addit. Planet	_______'
Total ( )	_______'
Ho	_____° _______'

So now you know how to obtain Ho. From the introduction you will remember that we need to calculate Hc as a step towards being able to find our position. So guess what comes next!

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10.6 Hc – (Height Calculated)

There are several steps in this process

1. Determine the GMT time and date.
2. Determine the LHA of the body.
3. Determine the Declination of the body.
4. Use the LHA and Declination to find Hc.

The best way to learn how to find the Hc is to work through an example. This will also give you the opportunity to become familiar with using the various sections of the sight reduction form and the Nautical Almanac. To keep it relatively simple we will use the Sun as the body. Although there are many commonalities when using the planets, the stars, and the moon there are also some additional factors that need to be taken into account. You will be introduced to these in a later section.

Scenario: Your DR position is 36° 13'N 009° 45'W. Those of you with good geography skills will recognize that you are in the Atlantic Ocean west of Gibraltar which is your next destination. The local date is 9th May 2007. You take a shot of the Sun's lower limb at 10-37-32. Your watch is 11 seconds fast and your height of eye is 10 feet. The sextant reads 67º 57.5' and the index error is 3.0' on.

GMT Time and Date

Sight Data	#072
Body	☉
Bearing	____º
DR Lat (N/S)	36º 13'
DR Lo (W/E)	009º 30'
Time	
Date	9 May 2007
WT	10-37-32
ZD (E-/W+) (+)	1
GMT WT	11-37-32
WE (f-/s+) (-)	___-11
GMT	11-37-21
GMT Date	9 May 2007

Remember all information from the Nautical Almanac must use the GMT Time and Date as the starting point.

This is sight number 072. The bearing to the Sun has not been entered as it would serve no useful purpose in this instance.

There are several ways you can determine the Zone Descriptor. If you cannot remember them look back at section 5

The timing diagram has not been used as the date is obviously the same in this case.

So look up the daily page in the Nautical Almanac for 9th May 2007 to find the GHA of the Sun at 11-37-21. This is illustrated in an extract from the sight reduction form in the next section.

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10.6.1 LHA of the Body

One common element in the NAO and H.O.249 sight reduction methods is the need for the LHA to be a whole number. This is achieved by manipulating the minutes part of the DR longitude such that when added or subtracted from the GHA the LHA becomes a whole number. Choose the minutes to be as close as possible to the minutes of the GHA. The difference between the DR longitude and the chosen Lo should never be more than 30'.

Almanac - LHA

SHA		____º____'
GHA ☉		
11h		345º 53.4'
37m 21s		9º 20.3'
v (+/-)	___ (planets, Moon)	
V corr. ( )		____'
Total GHA		355º 13.7'
Lo (E+/**W-**)		– 009º 13.7'
LHA		346º 00'

Here is the explanation of each line in this part of the form. You will get to use all the lines when we do some practical examples.

SHA = Sidereal Hour Angle is used with the stars so has been left blank. Notice the Sun symbol has been used; other symbols used are: ☾ Moon, ☆ Star, ♀ Venus, ♂ Mars, ♃ Jupiter, ♄ Saturn.

The hours, minutes, and seconds component of GHA are looked up in the Nautical Almanac as you have already seen. The v correction only applies to the moon and the planets and has been ignored here.

Total GHA is the sum of all the above.

The Lo degrees component is exactly the same as the DR position. The minutes component has been chosen to be numerically equal to the minutes of the GHA so that when subtracted (west longitude) the LHA is a whole number of degrees. This is the longitude part of your assumed position (AP).

10.6.2 AP Longitude / LHA Exercise

DR Longitude	GHA Sun	AP Longitude	LHA
076º 32.9'W	214º 57.3'		
158º 12.8'E	044º 34.2'		
124º 14.9'W	063º 41.7'		
076º 35.9'E	214º 57.3'		
169º 45.8'E	328º 10.5'		

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10.7 Declination of the Body

Almanac Declination	
11h	17º 19.3'
d (+/-) +0.7	
D corr. (37) +0.4'	
Dec. (N/S) 17º 19.7'N'	

In the Nautical Almanac daily pages look up the declination of the Sun at 11 hours. Take note whether the declination is increasing or deceasing as time goes on. Look at the bottom of the Sun column and note the *d* value. The sign is + if the declination is increasing and – if it is decreasing.
Go to the Increments and Corrections pages (grey edges on some Nautical Almanac editions) and turn to the 36/37 minutes page.

NOTE. For each minute there are 2 separate tables. The four left hand columns comprise one table that you have already used to find the time increment when calculating the GHA of a body. The three right hand columns comprise a completely separate table and are, in fact, one long column of data split into three to fit on the page. It is used to look up the *v* or *d* correction. There is no correlation between the two tables other than that they both relate to the particular minute value being used. To determine the correction to be used just look down the columns until you find the *d* value from the daily page. The corresponding correction is what is added or subtracted from the hourly declination value to adjust for the additional movement of the Sun related to the minute's time increment. In this example the *d* value of 0.7 gives a correction of 0.4'.

10.8 Process Review

Let's see where we are in the process of getting to Hc

1. Determine the GMT time and date. Done!
2. Determine the LHA of the body. Done!
3. Determine the Declination of the body. Done!
4. Use the LHA and Declination to find Hc. Not yet!

That's next. We will show examples of the NAO and HO 249 methods. The formulae that can be used with a scientific calculator are given in the appendices.

Remember your DR latitude is 36^0 13'N and you have just calculated the LHA to be 346^0.

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10.9 Determining the Height Calculated (Hc) NAO Method

Solution by NAO

Read from NAO tables first time:

Lat. **36°**	--->		A **11°17'**	**(+/-)**	B **53° 10'**	Z_1(**+**)	**81.7°**
LHA **346°**			Dec.	**(+/-)**	**17° 20'**		
					F **70° 30'**		

Read from NAO tables second time:

A°(rounded A)	**11°** -->		H **68° 09'**		P **59° 10'**	Z_2(**+**)	**61°**
F° (rounded F)	**71°**						
F' **30'**	P°**59** (rounded)	corr 1	**(-) 26'**			= (Z_1+Z_2) =	**142.7°**
A' **17'**	Z_2 **61°**(rounded)	corr 2	**(-) 08'**				
	(Hc = H + corr1 + corr2)	Hc =	**67° 35'**			Zn	**143°**
		Ho - Hc =	---> **05'**	(**toward**/~~away~~)			

If Ho > Hc plot intercept toward GP otherwise away

1. Enter the degrees of latitude (rounded to nearest degree), LHA, and the degrees and minutes of the declination.
2. Using Lat and LHA as the entry data look up A, B, and Z1 from the sight Reduction Tables (Nautical Almanac pages 286 to 315). Pay attention to the rules at the top of the page to determine the signs for B, Z1, and declination.
3. Calculate F by algebraically adding B to the declination.
4. Enter the degrees of A and F, rounded to the nearest degree.
5. Use these values as the entry data to the sight reduction tables a second time and look up the values of H, P, and Z2. Pay attention to the rule for the sign of Z2.
6. Enter the values of minutes of F, P (rounded to the nearest degree), minutes of A and Z2 (rounded to the nearest degree).
7. Turn to the Auxiliary Table in the Nautical Almanac (Pages 316 – 317). You will use this table twice in a similar manner to the sight reduction tables to determine the two additional correction factors (corr1 and corr 2).
8. Using F' and Pº as entry data look correction 1. Be careful to respect the sign conventions. For example for values of F' between 1 and 29 the correction will be positive. For values between 30 and 59 they will be negative.
9. Using A' and Z2 as entry data look up the value of correction 2. Again pay careful attention to the sign.
10. Algebraically add H, correction 1 and correction 2 to get Hc.
11. Algebraically add Z1 and Z2 to determine Z. Apply the rules from the bottom of the page to determine Zn. This is the direction from the AP to the Sun. You will use this when you plot your position.
12. The difference between Ho and Hc is the distance between the LOP and the AP. You will use this distance when you plot your position.

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10.10 Determining the Height Calculated (Hc) H.O.249 Method

	Solution by H.O. 249					
Lat. **36°**						
Dec **17° 20'**	Dec. is **same**/contrary name to Latitude					
LHA **346°**						
		from H.O.249	read:	H **67° 18'**	d **+ 51**	Z **143°**
			d (dec. diff.)	**+ 17'**		
			H + d corr. =	Hc **67° 35'**		
			Ho - Hc =	**05'**	(**toward**/~~away~~)	Zn **143°**
If Ho > Hc plot intercept toward GP otherwise away						

The previous method uses tables in the Nautical Almanac and has the advantage of not needing any additional tables. This method has the advantage of simplicity and speed and therefore is less susceptible to operator error. Only three relatively small books of tables are required. Volumes 2 and 3 are perpetual.

1. Enter the degrees of Latitude (rounded to nearest degree), Declination (not rounded), and LHA.
2. Select H.O.249 Vol 2 for latitudes between 0º and 40º or Vol 3 for latitudes 39º to 89º.
3. Select the appropriate latitude page. They are grouped by declination, 0º-14º and 15º-29º, and declination same or contrary name to the latitude.
4. Using latitude, LHA, and the degrees of declination as entry data look up the values of H, d, and Z. Note the polarity of d.
5. Look at the top or bottom of the page depending whether your latitude is North or South and apply the rules to determine Zn. This is the direction from the AP to the Sun. You will use this when you plot your position.
6. Turn to table 5. Using the d value and the minutes of declination as entry data look up the declination difference (dec diff). The sign will be the same as d.
7. Algebraically add H and dec. diff. to get Hc.

The difference between Ho and Hc is the distance between your LOP and the AP. You will use this distance when you plot your position.

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10.11 Height Observed (Ho)

We will plot this example in the next section. To do so we will need the Ho portion of the Sight Reduction form. You have already completed several examples; the solution is provided here for you as a reminder.

Sextant		Hs is the angle read off the sextant.
Hs	67º 30.5’	
IC (on - / off +)	–3.0’	Index correction and dip are applied to get Ha.
Ht of eye 10 (~~m~~/**ft**)		
Dip (-)	– 3.1’	
Ha	67º 24.4’	
Altitude Corrections		As this is a Sun sight there is only one altitude correction to be applied. Pay attention to which limb to use and which part of the year in the altitude correction table.
Alt. Corr	+ 15.6’	
UL Moon	~~-30~~’	
HP Moon ( )	________’	
Addit. Planet	________’	
Total (+)	15.6’	
Ho	67º 40.0’	

10.12 Review

Here’s what we now know. In the example the GP of the Sun is in a direction of 143º from the AP. If our position coincided with the AP the Sun’s altitude would have been 67º 35’ (Hc) but it measured 67º 40’ (Ho). So we are on a COP with a radius 5 miles smaller than that on which the AP lies. The center of our COP is also the GP of the Sun but we may be on a different azimuth. As long as the difference in distance between the AP and our position is small (less than 30 miles) this difference is insignificant and we can assume we are on the same azimuth.

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10.12.1 Sight Reduction Exercise

The body in all cases was Sun Lower Limb, times and dates are GMT, year is 2007.

In all these exercises the difference between Hc and Ho will never be more than 10’

Use the sight reduction forms that you will find in the appendix.

	DR L	DR Lo	Date	Time	Hs	IE	Ht (ft)
1	48°34.9’N	062°21.8’W	18 Jul	16:48:12	61° 04.0’	2’ on	6
2	51° 56’N	001° 51’E	13 Jun	10:56:29	59° 06.3’	2.3’ off	9.5
3	45° 37’N	044° 26’W	9 May	12:16:38	46° 38.3’	2.3 on	10
4	36° 24’S	097° 21’E	7 Aug	06:12:37	36° 37.9’	2.7 off	12
5	36° 42’N	045° 57’W	22 Feb	13:17:42	34° 57.9’	2.1 on	8
6	32° 17.8’S	060° 16.9E	5 Aug	07:14:17	39° 14.3’	0	10
7	10° 37’N	060° 18’E	21 Jun	11:14:22	42° 26.1’	0	10
8	10° 37’S	060° 18’E	20 Sep	11:14:22	37° 37.5’	1.2 on	8

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